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U. S. NAVAL AIR ENGINEERING CENTER

LAKEHURST, NEW JERSEY

GROUND SUPPORT EQUIPMENT DEPARTMENT
NAEC-GSED-119 03 MARCH 1978
CODE IDENT NO. 28638

CONTROL OF CORROSION
IN
GROUND SUPPORT EQUIPMENT

AIRTASK NO. A3400000/051B/7F41461400
WORK UNIT NO. 23

FINAL REPORT

PLATE NO. 11749A

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Reports the findings and presents recommendations resulting from an investigation made to determine the extent of and the reasons for corrosion on Navy aviation ground support equipment. Cost analysis data and results of an extensive on-site survey of Navy activities are also presented. Data relating to corrosion control methods, materials and equipment are included.

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I. SUMMARY

A. This report documents the findings and makes recommendations resulting from a three year RDT&E effort that explored the corrosion situation in Navy ground support equipment.

Initial efforts concentrated on determining the extent of the problem through research of historical data and on-site surveys of Navy and Marine activities both ashore and afloat. Existing facilities, methods and materials currently in use, as well as personnel attitudes and opinions were investigated and a photo record of over 700 corrosion incidents were obtained.

B. COST ANALYSIS. Approximate costs attributed to corrosion failures, in terms of manhours and parts replacement, were obtained through a thorough analysis of related entries in the 3M Data Bank. The totals obtained, while sometimes difficult to ascertain because of the wide latitude afforded to reporting custodians of GSE in the selection of "Malfunction Description Codes", can be conservatively placed at near 8 MILLION DOLLARS ANNUALLY with approximately 80% of that total being attributed to direct labor hours spent in maintaining or replacing paint systems. Based on the data accumulated during the course of this investigation and presented herein, those costs can be significantly reduced through the application of more durable corrosion barriers, an increased awareness of the corrosion problem at the design level, and the implementation of aggressive corrosion prevention/control programs at all levels of GSE maintenance.

C. SCOPE OF PROBLEM AND RECOMMENDED NEAR TERM ACTIONS. Study and analysis of available data reveals that the problem of corrosion on GSE is Navywide and encompasses virtually all types and models of common ground support equipment. Most adversely affected are those equipments that, because of their operational use and current GSE storage practices, spend practically all of their service lives outdoors, in a marine or coastal environment. Tow tractors, mobile electric power plants, maintenance platforms and jacks, weapons handling equipment, etc. are particularly affected.

Just as the corrosion problem is widespread, so are the causes. Design deficiencies, such as dissimilar metal contact, inadequate protective barriers, excessive access plates and doors, all contribute to the initiation of the corrosion process. For reasons generally attributed to a shortage of adequately trained personnel, and the absence of clearly defined corrosion prevention/control procedures at the organizational and intermediate levels of maintenance, the corrosion process, once initiated, is allowed to progress, generally unhampered, to a point where component failures occur and/or the overall appearance of the equipment becomes unacceptable. The normal practice at that point is to completely strip the remaining paint from the equipment by whatever means are available (disc-sanding, hand chippers, etc.) and then repaint it according to locally established customs that rely heavily on "old timer" expertise or experience gained through trial and error methods. According to available 3M data, the above described process accounts for the bulk of manhours expended in the GSE corrosion control effort.

It follows therefore that efforts to improve the current corrosion situation on GSE should have as their ultimate purpose, the elimination and/or

A

reduction of the manhours required to maintain corrosion barrier schemes at the organizational and intermediate levels of maintenance. Toward that end, the following actions, emerging from the results of this study appear necessary:

1. An increased awareness of the corrosion problem at the design level for the simple inclusion of corrosion inhibiting schemes. Specific design deficiencies, as derived from the study of the photo record obtained during the fleet survey are detailed in Section V, paragraph E 2.

2. The use of Military Standard 808 as the specification for final barrier coatings on GSE that is to be exposed to the elements during its service life should be curtailed. Polyurethane paint systems, as described in Table 11 with their greater durability and abrasive resistance should be specified for that purpose.

3. The development and issuance of specific guidelines for the materials, processes and equipment to be used at the various levels of maintenance for the prevention/control of corrosion on GSE.

4. The initiation of a program to test and evaluate newly developed products and equipments such as those listed in Tables 11, 12 and 13. The purpose of the program would be to identify those newly developed products and equipments that would prove economically suitable for use in the GSE corrosion control program.

D. STATE OF THE ART. Study of the current state-of-the-art as regards corrosion control reveals that several new equipments, materials and processes have been and are being developed as the result of intensive research in the industrial, academic, and military communities aimed at the reduction of costs attributed to corrosion of metals. Many of the products appear to be well suited for GSE applications and their use offers significant potential for long term dollar savings through a reduction of maintenance manhours and increased service life of the equipment.

Nylon II, an electrostatically applied nylon powder that is extremely abrasive resistant and virtually indestructible, is currently undergoing OPEVAL at the Naval Air Development Center in Warminster, Pa. This product, as well as several others (Table 12), when applied to the highly abrasion prone horizontal surfaces of tow tractors, spotting dollies, etc. could serve to eliminate the severe corrosion problems now being encountered on those units.

Also in the area of new equipments is the Hydroblaster 610-E now undergoing operational evaluation under the control of NAEC-GSED CODE 92713. Using water-borne particulate under high pressure (10,000 PSI), the Hydroblaster is proving successful in complete stripping operations. However, because of safety implications resulting from the ultra high pressures involved, its use is necessarily limited to depot level facilities. Other similar equipments, available on the commercial market, are listed in Table 14.

E. OTHER FACTORS AFFECTING GSE CORROSION. Other than the readily apparent near term solutions discussed above, several other shortcomings exist in the

GSE corrosion control program as it currently functions. While not necessarily within the scope of this study, the impact of these program weaknesses on the ability to effectively control corrosion on GSE is considered sufficient to warrant comment herein. Some of the more prominent of these are:

1. Training. Formal training courses for corrosion control are organized and designed almost exclusively for the aircraft corrosion control program. See Table 8. As such, the curriculum content of the schools deal primarily with metals associated in aircraft manufacture. GSE, constructed primarily of ferrous metals, requires substantially different treatments. Also, school entry pre-requisites appear to be designed for those Navy ratings responsible for corrosion control on aircraft.

2. Maintenance Data Collection System. One of the necessary elements for the effective control of corrosion on GSE is the ability to closely monitor the equipment during its service life to provide early detection of recurring corrosion related failures and initiate corrective measures. The Maintenance Data Collection System is the accepted mechanism for achieving that purpose in the Navy.

In the course of this study, attempts to accurately assess the costs for corrosion related failures, using data as collected by the MDCS, were often frustrated by the seemingly inaccurate selection of Malfunction Description Codes by reporting custodians of GSE. For reasons believed to be caused by (1) inadequate training in corrosion identification or (2) operationally imposed expediency in completing the required "paper work", corrosion related failures are often masked under such "catch-all" codes as "BROKEN" or "SHORTED" etc. Part of the overall solution to the GSE corrosion problem should include the necessary actions to insure accurate reporting of GSE corrosion related failures.

F. GEOGRAPHIC CONSIDERATIONS. Geographical location, while an important consideration in the development of local corrosion control programs, has little significance at the design level when selecting the corrosion barrier schemes to be applied to GSE. Corrosion rates do differ among the various locations in which GSE operates; however, because of continuing and unpredictable changing operational needs, equipments are often shifted to many locations during their service life. Also, inasmuch as Navy GSE must operate almost exclusively in a hostile, near-ocean environment, only the most durable and corrosion resistant barriers will perform satisfactorily.

G. ELECTRONIC AND ELECTRICAL COMPONENTS. Because of the unusual complexities involved and the subtle nature of corrosion on electronic and electrical components, entirely different methods of corrosion detection, protection and repair are involved. Two recent Navy sponsored studies on the subject of avionics corrosion, references (3) and (4), indicate that for the reasons stated above, a separate corrosion control manual, dealing exclusively with avionics corrosion control, should be developed. Corrosion control measures for electronic and electrical components on GSE will be the subject of one chapter in a forthcoming GSE Corrosion Control Manual.

II. PREFACE

A. Largely ignored until only a relatively few short years ago, corrosion of ground support equipment in the Navy began to receive increased attention as procurement costs of new equipments soared and service life extensions of existing equipments became necessary. Also contributing to this increased awareness were the highly visible benefits being reaped from the Navy's dynamic and aggressive aircraft corrosion control program.

Thus prompted, and with the sponsorship of the Naval Air Systems Command, exploratory probes were made to determine the extent of the problem. The results obtained, summarized in reference (1), clearly indicated a problem of significant magnitude. The dollar cost for maintenance manhours expended and for parts replacement, while in some cases difficult to accurately assess due to a lack of historical data, reaches into the millions each year.

A follow-on in depth effort was then initiated under the sponsorship of the Naval Air Systems Command to determine the principal causes of the corrosion problem and, as a parallel effort, investigate the current state-of-the-art in corrosion prevention and make recommendations for its application to Navy ground support equipment. The results of those efforts are presented in reference (2) and herein.

III. TABLE OF CONTENTS

IV. LIST OF TABLES AND FIGURES

V. GSE CORROSION CONTROL

A. INTRODUCTION. Corrosion can be defined as the deterioration of a metal by reaction to its environment. That deterioration is either accelerated or retarded by the nature of the environment in which it is placed. At normal atmospheric pressure the moisture in the air is sufficient to initiate corrosive action if suitable protection is not afforded. Wind, rain, temperature and material composition are but some of the factors that influence the rate of corrosion.

Ground Support Equipment (GSE) constructed principally of ferrous metals is highly susceptible to the ravages of corrosion, especially in the Navy where it must stand up to salt spray and mist, ocean sunshine, and carrier and aircraft stack and exhaust gases.

Corrosion protection for GSE as it currently exists consists primarily of a relatively fragile paint film acting as a barrier between the corrosive elements and the raw metals. That barrier does provide reasonable initial protection; however, when placed in an operational environment, it immediately becomes highly vulnerable to damage. Equipment such as wheel chocks, chains, hoses, etc., indiscriminately thrown upon or dragged across GSE surfaces easily penetrate the barrier and corrosive action begins. If left unchecked, it now begins its relentless path to ultimate destruction of the component.

From the beginning of Naval Aviation until just a few short years ago, corrosion was looked upon as "something that must be lived with" and corrosion control efforts were limited to "chip and paint" or "remove and replace" procedures. As technology advanced and support equipment became more complex and far more costly to procure and repair, corrosion prevention as a means of extending the useful service life of GSE began to receive increased attention.

The aims of this study therefore were first, to determine the extent of the GSE corrosion problem as it currently exists and its impact on operating funds; second, evaluate the current state-of-the-art corrosion prevention/control schemes available or being developed by the industrial, scientific, and military communities; and third, through evaluation of the information, provide guidelines for the prevention and control of corrosion in ground support equipment.

B. UNDERSTANDING CORROSION. Corrosion, as it affects ground support equipment is not easily classified. It takes many forms from many causes and the chemical processes involved are highly complex. The classic textbook treatments on corrosion and its causes are readily available to the engineering community. Its discussion herein will be limited to that necessary for ease of understanding.

1. Electrochemical Process. Corrosion is the deterioration of metal in reaction to its environment. Most corrosion is electrochemical in nature. Before electrochemical corrosion can occur, four conditions must exist:

a. A metal susceptible to corrosion must be present. This metal acts as the anode.

b. A metal or an area less prone to corrosion than the first must be present. This metal or area acts as the cathode.

c. Both metals or areas must be in contact with the same liquid to form a continuous electron path.

d. The anode and the cathode must be in electrical contact.

These four conditions are illustrated in Figure 1. Elimination of any of the four will halt the electrochemical process. The most common methods used are:

(1) Elimination of the liquid path by placing a barrier such as paint between the surface and the liquid (electrolyte).

(2) Reducing the potential difference between the anode and the cathode by plating one of the metals with a different metal.

(3) Removing electrical contact by insulating against direct contact of dissimilar metals.

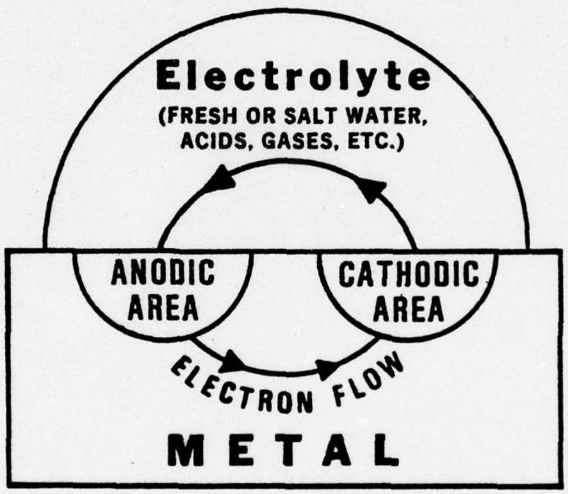

Figure 1. CORROSION MODEL

2. Types of Corrosion Affecting GSE. The principal forms of corrosion affecting GSE are galvanic or dissimilar metal corrosion and concentration-cell corrosion.

a. Galvanic Corrosion. Galvanic corrosion is a form of electrolytic corrosion that occurs when dissimilar metals are in electrical contact and joined by the same solution or electrolyte. The resulting corrosion is a function of current flow, which, in turn, is a function of (1) the difference in the metals potential, and (2) the ratio of the area of the anodic metal to the area of the cathodic metal.

Table I is a listing of selected metals in the order of their relative potential in sea water environment. The list begins with the more active (anodic) metal and proceeds down to the least active (cathodic) metal. Generally, the closer one metal is to another metal in the series, the lesser

the tendency to corrode. On the other hand, the coupling of metals distantly located in the series will result in intense galvanic action.

Table 1. GALVANIC SERIES OF SELECTED METALS IN SEAWATER

ACTIVE (ANODIC) ↓

Magnesium (Mg)
Mg Alloy AZ-31B
Mg Alloy HK-31A
Zinc (pl. hot-dip, die cast)
Beryllium (hot pressed)
Aluminum (Al) 7072 cl. on 7075
Al alloy 2014-T3
Al alloy 1160 H14
Al alloy 7079-T6
Cadmium (pl.)
Uranium (depl.)
Al alloy 218 (die cast)
Al alloy 5052-0
Al alloy 5052-H12
Al alloy 7151-T6
Al alloy 5456-0, H353
Al alloy 5052-H32
Al alloy 1100-0
Al alloy 3003-H25
Al alloy 6061-T6
Al alloy 7071-T6
Al alloy A360 (die cast)
Al alloy 7075-T6
Al alloy 1100-H14
Al alloy 6061-0
Indium
Al alloy 2014-0
Al alloy 2024-14
Al alloy 5052-H16
Tin (pl.)
Stainless steel 430 (active)
Lead
Steel 1010
Iron, cast
Stainless steel 410 (active)
Copper (pl.)
Nickel (pl.)
Chromium (pl.)
Tantalium
Stainless steel 350 (active)
Stainless steel 310 (active)
Stainless steel 304 (active)
Stainless steel 430 (passive)
Stainless steel 410 (passive)
Stainless steel 17-7 pli (active)

(Cont)

Tungsten
Niobium (Columbine) 1%Zr
Brass, yellow, 268
Cranium (depl.) 8% Mo.
Brass, Naval, 464
Yellow Brass
Muntz metal 280
Brass (pl.)
Nickel-silver (18% Ag)
Stainless steel 316L (active)
Bronze 220
Everdur 655
Copper 110
Red brass
Stainless steel 347 (active)
Molybdenum, Comm pure
Copper-Nickel 7151
Admiralty brass
Stainless steel 202 (active)
Bronze, phosphor 534 (B-1)
Stainless steel 202 (active)
Monel
Stainless steel 201 (active)
Steel alloy Carpenter 20 (active)
Stainless steel 321 (active)
Stainless steel 316 (active)
Stainless steel 309 (passive)
Stainless steel 17-7 pli (passive)
Stainless steel 304 (passive)
Stainless steel 321 (passive)
Stainless steel 201 (passive)
Stainless steel 286 (active)
Stainless steel 316L (passive)
Steel alloy AM355 (active)
Steel alloy 202 (active)
Steel alloy, Carpenter 20 (passive)
Steel alloy AM350 (passive)
Steel alloy 286 (passive)
Titanium 5Al, 2.5 Sn.
Titanium 13V, 11Cr, 3Al. (annealed)
Titanium 8Mn.
Titanium 3Al, 13V, 11Cr (h.t + aged)
Titanium 75A
Stainless steel 350 (passive)
Graphite

NOBLE, LESS ACTIVE (CATHODIC) ↑

The ratio of the cathodic area to the anodic area also influences the rate of attack. When there is a large cathode in contact with a small anode the corrosion attack on the anode is more concentrated and far more rapid.

b. Concentration Cell Corrosion. Concentration cell corrosion is the localized, accelerated attack that occurs when two or more areas of metal are in contact with a non-uniform electrolyte or environment. This attack, electrochemical in nature, occurs because of differences in concentrations of metal ions or of dissolved gasses (e.g., oxygen) resulting in differences in potential on the surface of the same metal or surfaces of electrodes consisting of the same metal. (See Figure 2.)

Concentration cell corrosion may be further divided into three types: (1) Metal ion concentration-cell corrosion, (2) oxygen concentration-cell corrosion and, (3) active passive-cell corrosion.

Metal ion and oxygen concentration cells usually occur in faying surfaces. crevices and under surface soils. A high metal ion concentration normally occurs in the crevice area where the electrolyte is relatively stagnant and a lower ion concentration occurs adjacent to the crevice area. A difference in potential will therefore exist and corrosion will occur where the metal ion concentration is the lowest (adjacent to the crevice). In contrast, oxygen concentration cells have the highest concentration adjacent to the crevice and corrosion will occur in the crevice area.

Active-passive cells are encountered on metals that rely on oxidation for corrosion protection such as stainless steels and aluminum alloys. Corrosion will initiate where the passive film is destroyed and active metal is exposed. A difference in potential results and the active metal will corrode. Since most of the metal is still protected by a passive film, a large cathode to anode ratio exists and rapid pitting will occur.

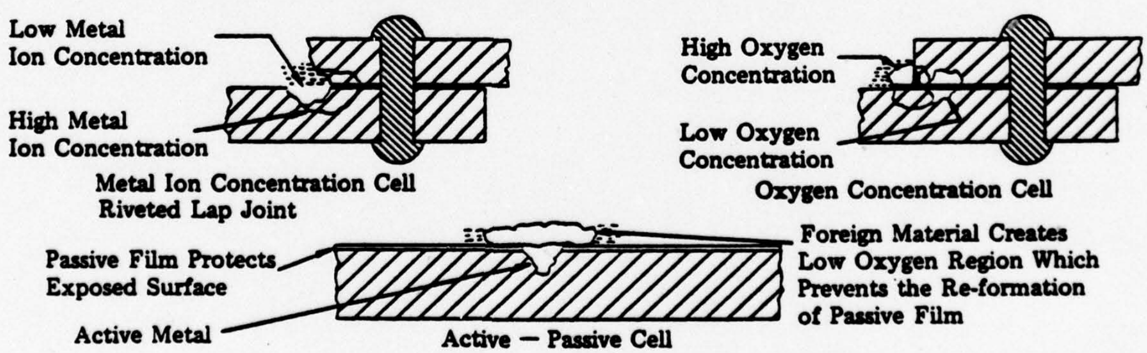

Figure 2. CONCENTRATION CELL CORROSION

c. Stress Corrosion. Stress corrosion failure results from the combined effects of tensile stress and corrosion. (See Figure 3.) It can be produced by straining, grinding, welding, quenching or cold working. The

applied stresses can be localized, uniform static or cyclic. Combined stresses, sufficient to initiate stress corrosion cracking may result from a combination of the above stresses. Stressed areas are anodic to unstressed areas under corrosive conditions. The two types of failures associated with stress corrosion are cracking and fatigue failures.

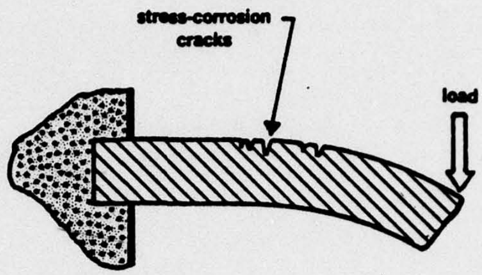

Figure 3. STRESS CORROSION CRACKING

d. Fretting Corrosion. Fretting corrosion occurs when two metal surfaces are in contact, under load, and subjected to vibration or slight relative motion. (See Figure 4.) The surfaces must be in relative motion and oxygen or air must be present. Bolts, flanges, key shafts etc. which might encounter vibration can be affected if the contacting surfaces undergo slight relative motion. Fretting corrosion is characterized by the presence of surface discoloration, depressions or pits. In the case of ferrous alloys, widely in use on GSE, dark brown iron oxides issue from the interface. Piano hinges are especially vulnerable to this type of corrosion.

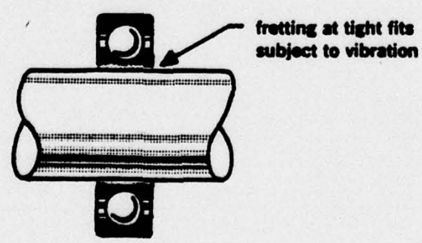

Figure 4. FRETTING CORROSION

e. Pitting Corrosion. Pitting is a common and severe form of localized corrosion. Thin metal sheets or plates are especially vulnerable to this type of attack. (See Figure 5.) The initiation of pitting corrosion occurs because of incomplete film or coatings on the metal surfaces or the presence of substances which partially shield small areas on the metal surface. Corrosive agents such as chlorides accelerate the attack.

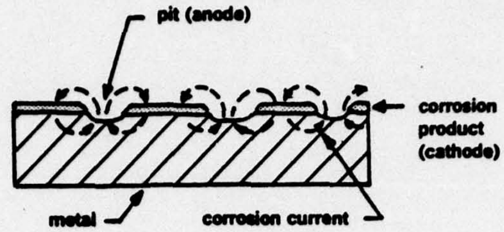

Figure 5. PITTING CORROSION

f. Intergranular Corrosion. Intergrannular corrosion occurs in boundaries between grains and crystals in metals. (See Figure 6.) The boundary areas are usually anodic to the grains and, as a result, if sufficiently wide potential differences exist, rapid and concentrated corrosion will occur. Exfoliation is a form of intergranular corrosion and is the result of corrosion products causing stress below the metal surface which in turn, causes bulges in the surface.

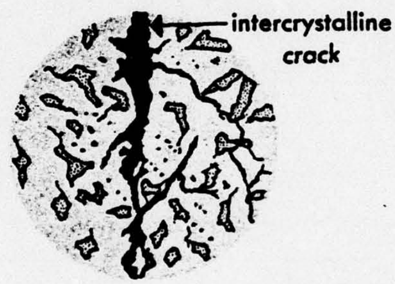

Figure 6. INTERGRANULAR CORROSION

3. Electronic and Electrical Components. Corrosion of electronic and electrical components is far more subtle in nature than the highly visible corrosion encountered on structural components of GSE. Short circuits, changes in constants or values, intermittent operation, impaired mechanical action, current leakage are only a few of the results that are caused by the presence of corrosion on contacts, connectors, plugs, jacks etc. The methods, procedures, and materials used in corrosion control on electronic and electrical components are far more sophisticated and complex than those discussed within this report. References (3) and (4) report on the results of two recent studies on the subject of avionics corrosion. While these studies do not specifically address GSE, the corrosion problems as well as the solutions are essentially identical.

As is the case in all corrosion problems, moisture, acting as an electrolyte is the principal cause of corrosion in electronic and electrical components. Adequate protective measures in the form of seals, gaskets, covers etc., are normally applied at manufacture; however, once placed in service, these protective devices quickly fall victim to the severe operational environment. Repeated openings of the access covers and plates for maintenance and other reasons eventually destroy the integrity of the unit. In a survey of field failures conducted by the Air Force, 35% were directly

caused by humidity. Based on information gathered during this study, that figure is considered valid.

Other than the obviously vulnerable electronic components found on equipment such as the mobile electric power plants, electrical components installed on virtually all mobile equipment are also highly susceptible to failures due to corrosion as attested to by the number of photos related to electrical failures gathered during the fleet tour. See reference (2).

Cleaning of electronic equipment is a complex procedure. Grease and dirt must be removed without affecting the low-melting waxes, dialectric materials, seals, plating, etc., used in the construction of electronic circuitry. Cleaning compounds that are safe for one material may adversely affect the adjacent materials. For example, ultrasonic cleaning is generally an effective method for cleaning mechanical and electrochemical components, but is not as satisfactory when applied to semiconductors and other delicate parts.

Because of the extreme sensitivity of electronic and electrical components and the unusual complexities involved in their cleaning and protection, the Corrosion Preventive Maintenance Program must be organized so as to treat that aspect in a distinctly separate manner. The extensive efforts now underway to combat corrosion in avionics should be expanded to include all ground support equipment that incorporate electronic components.

C. COST OF CORROSION. The overall cost for corrosion in the industrial and military communities for 1965 was estimated to be EIGHT BILLION DOLLARS (Reference 5). In view of the rapid acceleration of costs during recent years, for both men and materials, it is reasonable to assume that the same estimate would increase at least threefold for 1977. The obvious economic and military preparedness impacts are the principal reasons behind the extensive research now in progress on the subject of corrosion and its prevention.

1. 3M Data Searches. To what extent does corrosion on GSE contribute to those totals? The answer, vital when evaluating the relative economical merit of new corrosion control methods, materials and processes, can be best perceived through analysis of related entries from the data bank of the Maintenance Data Collection System (MDCS). While the data contained therein is somewhat deceptive because of the wide latitude afforded to reporting custodians of GSE in selecting "Malfunction Description Codes", it does provide a fairly accurate, conservative assessment of the overall cost in terms of manhours expended and procurement of parts. Three separate searches were initiated in the course of this investigation:

a. In the first search, an arbitrary two year sampling period (July 1972 to August 1974) was selected for a typical sampling of 3M corrosion data entries. Since the aims of this initial search were primarily to obtain geographical correlation data, the cost data obtained was somewhat limited. However, it did provide an insight into the overall dollar cost and provided the impetus for the later, more definitive searches.

Reference (1) contains a lengthy, detailed summary of the results of the first 3M Data search. Over 600 categories of ground support equipment were examined. Only those activities at all carrier and station sites that had entered at least 250 or more corrosion maintenance manhours under specified

code numbers were searched. All entries under the following Malfunction Description Codes, taken from Reference (3) were examined:

117 Deteriorated
170 Corroded

Similarly, all entries under the following Support Action Code were examined:

040 Corrosion Control

The data searched represented full span organizational, intermediate, and depot level maintenance reporting. Under the limitations specified above, a total of approximately 330,000 maintenance manhours were recorded for the two year period. Applying an average cost figure of $20.00 per hour as derived from the current official cost figures placed on GSE maintenance of $14.69 (SHIP) and $23.63 (SHORE), the total dollar cost for maintenance manhours obtained from the limited initial search is 6.6 MILLION DOLLARS for the two year period or 3.3 MILLION DOLLARS ANNUALLY.

Table 2 is a summary of the data obtained in the first search for ten selected categories of ground support equipment. The categories listed represent the so-called "heavies" in the corrosion picture and account for 19% of the total manhours reported.

The wide disparity (3.5 to 1) in the number of units reported on (column 4) and the number of units existing in the Navy inventory (column 3), as obtained from Reference (3) is assumed to be the result of three possible reasons: the limitations of the survey (250 or more hours); units in storage awaiting deployment such as at Marine Corps Headquarters and Maintenance Squadrons (H&MS); and units out of service awaiting survey or other administrative actions.

b. In an attempt to more clearly define the manhour cost data and to verify the findings of the initial search, a second 3M data search was made wherein <u>all</u> corrosion related manhours reported to have been expended by reporting activities were obtained for a recently concluded one year period. The results shown in Tables 3 and 4 are all inclusive and accurately represent the total yearly cost for corrosion manhours as reported in the Maintenance Data Collection System. A $20.00 per hour cost has been used to arrive at the totals shown.

The total cost for the most recent one year period for corrosion maintenance manhours on ground support equipment can thus be established at 7.3 MILLION DOLLARS YEARLY as a minimum.

The reason for the difference in total reported costs resulting from the first two searches is that in the first search, only Support Action Code 040 was included whereas in the second search, codes 040 through 049 were rightfully included.

Another vital point that must be considred in the determination of the true manhour cost for corrosion on ground support equipment is the interpretation, at the local levels, of which Malfunction Description Code to apply when reporting failures. While the above analysis was limited to the two

Table 2. CORROSION MAINTENANCE MANHOURS FOR SELECTED CATEGORIES (TWO YEARS)

EQUIPMENT CATEGORY	TYPE	1 EQUIP-MENT CODE	2 NUMBER ACTIVITIES REPORTING	3 NUMBER UNITS NAVY INVENTORY	4 NUMBER UNITS REPORTED	5 TOTAL MANHOURS REPORTED	6 AVERAGE HOURS PER UNIT
Mobile Electric Power Plants	NC-5A/B	GABC/D	4	41	31	1701	55
	NC-10	GACB	5	136	111	3470	31
	NC-12	GACC	1	78	4	274	68
	NC-8A	GAC6	10	861	274	6054	23
	NC-2	GACG	8	137	71	4223	59
				1253	491	15722	
Air Start Units Enclosures, Pods Etc.	GTC-85	GBGC	4	86	93	1423	15
	NCPP-105	GBHE	1	185	19	258	13
	GTC-85	GBGD	8	66	152	3013	20
				337	264	4694	
Air Conditioners	NR-3A	GECE	1	16	2	1081	540
	NR-2B	GECU	3	81	19	1554	82
	NR-5C	GECZ	2	72	9	935	104
				169	30	3570	
Air Compressors	NHPC-4	GFBA	1	47	4	320	80
Hydraulic Test Stands	AHT-64	GGE3	6	43	43	3040	71
	HCT-10	GGLD	1	83	1	255	255
				126	44	3295	
Oxygen Servicing Equipment (Tank)	NO-4	GJCE	1	178	13	1185	91
	NO-2	GJCJ	3	234	19	881	46
	NO-7	GJCM	1	109	4	344	86
	500 Gal.	GJCW	5	14	33	4971	151
				535	69	7381	
Nitrogen Servicing Units	NAN-2	GJCV	4	212	26	1764	68
	NAN-3	GJC2	1	106	4	339	85
				318	30	2103	
Weapons Handling Equipment	AERO 47A	GMFC	1	87	20	267	13
	A/S32K-1	GMFD	4	186	57	2182	38
	AERO 51B	GMGM	1	508	12	623	52
				781	89	3072	
Tow Tractors	TA-18	GPCK	4	194	42	1061	25
	MD-3	GPCL	7	408	113	4746	42
	JG-75	GPCY					
	TA-75	GPC1	13	1202	297	11508	39
				1804	452	17315	
Spotting Dolly	SD-1	GPC2	9	94	49	5200	106
TOTALS		28		5609	1522	62672	41.17

Table 3. SUPPORT ACTION CORROSION CONTROL MANHOURS
(FROM 3M DATA BANK) (ONE YEAR 1976-77)

SUPPORT ACTION CODE	CODE APPLICATION	TOTAL HOURS REPORTED	COST
040	Corrosion Control - Used when none of below codes apply	56,170	$1,123,400
041	Enclosures	19,506	390,120
042	Installed Power Plants	5,032	100,640
043	Propeller/Helicopter Dynamic Components, Cables Stands etc.	135	2,700
044	Utilities - All utility Systems except oxygen	1,916	38,320
045	Electronics, Electrical Batteries, Wiring etc.	29,396	587,920
046	Photographic Equipment	380	7,600
047	Armament/Ordnance, Weapons and Weapons System Suspension and Release Mechanisms	77,118	1,542,360
048	Safety/Survival Oxygen Systems and Ejection Seats	4,984	99,680
049	Preservation or Long Term Stowage	5,372	107,440
	TOTALS	200,009	$4,000,180

Table 4. MALFUNCTION CORROSION CONTROL MANHOURS
(FROM 3M DATA BANK) (ONE YEAR 1976-77)

MALFUNCTION DESCRIPTION CODE	COMMON TERM	HOURS REPORTED	COST
170	Corroded	145,329	$2,906,580
117	Deteriorated	15,381	307,620
	TOTALS	160,710	$3,214,200

obvious corrosion codes (117, deteriorated and 170, corroded), several other codes, from among the more than 180 available, can be selected that would in fact be masking corrosion related malfunctions. Table 5 below summarizes some examples of Malfunction Description Codes that, to some unknown degree, impact on the total cost for corrosion.

Table 5. OTHER MALFUNCTION DESCRIPTION CODES

MALFUNCTION DESCRIPTION CODES	MALFUNCTION DESCRIPTION	HOURS REPORTED
020	Worn, stripped, chafed, frayed	78,879
070	Broken, burst, ruptured, punctured, torn, cut	186,141
190	Cracked, crazed	9,940
520	Pitted	364
	TOTAL	275,374

The major reasons for the improper selection of the accurate reporting code are the complexity of the corrosion process and a lack of training. *Corrosion, in most cases, is simply* not obvious to the mechanic who must make the judgement as to the cause of failure.

c. In the third search, initiated in an attempt to establish the dollar cost for parts replacement due to corrosion, all reported parts failures for the entire spectrum of GSE occuring during the most recent 12 months period were obtained. The Malfunction Description Codes analyzed were:

117 DETERIORATED
170 CORRODED
070 BROKEN ETC.

The 070 code has been included to indicate its widespread use in the reporting of failures.

Table 6. FAILED PARTS (FROM 3M DATA, 1 YEAR)

MALFUNCTION DESCRIPTION CODES	TOTAL FAILED PARTS	COST
117	2,172	$ 43,440
170	6,707	134,140
070	59,825	1,196,500

To arrive at a per part dollar cost, 296 failed parts on the NC-8A Mobile Electric Power Plant were analyzed. Cost data from a 1973 provisioning list (the latest available) was applied and resulted in a per part dollar cost of $12.34. Allowing a conservative 10% increase per year, the average cost per part is placed at $20.00 for 1977. Applying that figure to the totals shown in Table 6 for the 117 and 170 codes only, results in a yearly cost for parts replacement due to corrosion over the entire spectrum of GSE at $177,580. When considering the number of GSE units that exist in the Navy inventory (approximately 20,000) the validity of that total must logically be considered suspect.

In summary, based on available data from the Maintenance Data Collection System, the cost for corrosion on ground support equipment, in terms of manhours and parts failures can, as a minimum be placed at 7.4 MILLION DOLLARS ANNUALLY. The true figure is perhaps closer to 12 MILLION DOLLARS because of the aforementioned possible inaccuracies in the selection of Malfunction Description Codes. Inasmuch as the bulk of the total cost is currently being expended for maintenance manhours vice parts procurement, it appears that significant savings could be achieved through the application of more durable protective finishes for GSE.

D. FLEET SURVEY.

1. In view of the many questions left unanswered following the 3M data analysis, it was necessary to initiate a fleet survey to gather first-hand data which, when coupled with the "on-hand" information, would define the base from which rational, cost effective solutions could be developed.

Fifteen NAS/MCAS sites, on both the East and West coasts, were visited during the survey as well as one CVA, which, at the time of the survey, had recently returned from a long deployment to the Mediterranean and the North Atlantic Ocean. A complete listing of the sites surveyed along with comparitive totals of equipments surveyed and corrosion incidents recorded are presented in Table 7.

2. Photographic Record. A total of over 700 photographs of corrosion incidents were gathered in the course of the survey. These provided the more dramatic evidence of the extent of the existing corrosion situation on Navy GSE. Representative samples from this photographic record are reproduced and identified in Appendix B.

The preponderance of the collected photos were made at East Coast sites and while somewhat indicative of a higher corrosion susceptibility in the Eastern near ocean environment, due to higher humidity and ocean salinity, the random methods used in the collection of the photos as well as time and budget considerations were the principal reasons for the disparity. Corrosion occurs regardless of the geographic location and only the rate of corrosion is thusly affected.

Analysis of the survey data and photo record verified the findings of the 3M data analysis in that the same high usage, common GSE equipments emerged as the principal victims of corrosion. Tow Tractors, Mobile Electric Power Plants, Maintenance Platforms, Air Conditioners, and Weapons Handling Equipment account for more than 50% of the accumulated photos. With few

exceptions, these type units spend virtually all of their useful service lives outdoors exposed to the elements.

Table 7. GSE CORROSION PHOTO SUMMARY

	SITE	EQUIPMENT ITEMS SURVEYED	PHOTOS TAKEN	TOTAL CORROSION INCIDENTS RECORDED
WEST COAST				
	AIMD, NORTH ISLAND	14	20	75
	NARF, NORTH ISLAND	8	11	30
	NAS, MIRAMAR	22	31	83
	MCAS, EL TORO	14	19	44
	NAS, MOFFET FIELD	8	19	51
	NARF, ALAMEDA	12	25	55
	NAS, WHIDBEY ISLAND	5	8	21
	TOTAL	85	133	359
	SITE/AVERAGE	12	19	51
EAST COAST				
	NAS, JACKSONVILLE	39	135	576
	NAS, PENSACOLA	12	98	408
	NAAS, WHITING FIELD	5	14	56
	NAS, KEY WEST	24	84	330
	MCAS, BEAUFORT	18	101	381
	NAS, NORFOLK	14	74	270
	NAS, OCEANA	9	47	177
	TOTAL	121	553	2,198
	SITE/AVERAGE	17	79	314
SHIPBOARD SURVEY				
	USS INDEPENDENCE	11	17	74

3. Open Skies Storage. Open skies storage, the norm for common GSE at virtually all sites visited, is considered the principal contributor to the existing GSE corrosion problem. That view is corroborated by all operating and maintenance personnel questioned during the survey. It is not uncommon for GSE to be stored under open skies, awaiting issue, immediately following delivery from the manufacturer. Often, parts must be replaced or refurbished before a new piece of equipment can be issued because of the open skies storage practice and the lack of effective corrosion preventive measures. Following issue, the use and storage of the equipment is simply a continuation of the exposure deterioration with the added impact of the operating hazards.

The practice of storing GSE in outside areas appears to be, in many instances, a matter of convenience rather than necessity. While conditions and facilities vary widely from site to site, at many of the locations surveyed it appeared that ample storage, inside hangars, was available but not utilized for the storage of GSE. In view of the major impact of open skies storage on GSE corrosion, it is recommended that surveys be initiated by local base commanders that would serve to identify and make available indoor storage areas for GSE where possible.

4. Organization and Personnel. Formally established corrosion control programs for GSE as required by OPNAVINST 4790.2A "NAVAL AVIATION MAINTENANCE PROGRAM", Reference (6), are intended to be, and were usually found to be, administratively organized as a natural extension of the aircraft corrosion control program. In reality, however, for reasons generally attributed by supervisory personnel to personnel and material shortages, the number of manhours that can be devoted to corrosion control on GSE is severely restricted. The usual result is that corrosion control efforts for GSE are limited to asthetic painting that satisfies an immediate need to improve equipment appearance.

At all sites visited, the common practice at the intermediate level of maintenance is to assign one individual to corrosion maintenance on GSE. At some activities that lone individual could be responsible for hundreds of pieces of GSE. Supplemental help is usually obtained from tenant activities when a "drive" to upgrade the appearance of GSE is ordered. Without exception, the quality and extent of corrosion control on GSE is directly dependent upon the experience and dedication of the man responsible.

There is a wide divergence of methods, materials, and processes now in use for the removal of corrosion and the reapplication of paint systems. The selection of procedures relies heavily on "old timer" expertise, availability of materials, and experience gained from the Aircraft Corrosion Control Program. In all cases, however, paint remains the only deterrent to corrosion on GSE and corrosion control programs consist of the endeavor to maintain adequate paint coatings.

5. Available Training and Manuals. Inasmuch as formal corrosion control training would play a major role in any future efforts to improve the existing GSE corrosion control maintenance programs, a review of available formal training courses on the subject was made. Table 8 is a summary of courses offering formal training in corrosion control as listed in the Catalogue of Navy Training Courses (CANTRAC) as of July 1977, reference (7).

Table 8. LIST OF NAVY CORROSION CONTROL COURSES

COURSE	TITLE	LENGTH	LOCATION	RATINGS	PREREQUISITES
M-000-0001	CORROSION CONTROL	5 DAYS	NARF NORVA NARF PSCLA NARF JAX NARF CHERRY PT.		GRADUATES OF NAMTD CORROSION CONTROL COURSE C-000-3171.
C-000-0330	AIRCRAFT CORROSION CONTROL	7 DAYS	NARF ALAMEDA NARF NORTH ISLAND		GRADUATES OF NAMTRADET 40 HOUR CORROSION COURSE OR COMPLETION OF AM(B) SCHOOL IN PAST TWO YEARS.
C-000-3177	CORROSION CONTROL YXB	3 DAYS	ALL NAMTD's		ALL NAVAL PERSONNEL INVOLVED IN THE MAINTENANCE OF NAVAL AIRCRAFT
C-000-3184	BASIC CORROSION CONTROL FAMILIARIZATION	1 DAY	NAMTD ALAMEDA		FOR AVIATION PERSONNEL NOT SPECIFICALLY ASSIGNED TO CORROSION CONTROL TEAMS
C-000-3192	CORROSION CONTROL	1 DAY	NAMTD NORTH ISLAND NAMTD MERIDIAN		ALL AVIATION PERSONNEL ASSIGNED TO MAINTENANCE OF NAVAL AIRCRAFT
E-603-1570	A-7C/E CORROSION CONTROL TEAM MEMBER	40 DAYS	VA-122 NAS LEMOORE, CA	AMS-ADJ, AE E2 to E5	QUOTA CONTROL - VA-122
E-603-1571	A-7C/E CORROSION MAINTENANCE SUPERVISOR	47 DAYS	VA-122 NAS LEMOORE, CA	E5 to E7	AM "A" SCHOOL OR EQUIVALENT
E-603-1873	EA-6B CORROSION MAINTENANCE SUPERVISOR	50 DAYS	VAQ-129 NAS WHIDBEY ISLAND	E6 to E7	QUOTA CONTROL - VAQ-129 AMS "A" SCHOOL OR EQUIVALENT
E-603-1874	EA-6B CORROSION CONTROL MAINTENANCE TEAM LEADER	43 DAYS	VAQ-129 NAS WHIDBEY ISLAND	E5 to E6	QUOTA CONTROL - VAQ-129 AMS "A" SCHOOL OR EQUIVALENT
E-603-1875	EA-6B CORROSION CONTROL MAINTENANCE CREWMAN	29 DAYS	VAQ-129 NAS WHIDBEY ISLAND	E2 to E5	QUOTA CONTROL - VAQ-129 AMS "A" SCHOOL OR EQUIVALENT
E-602-1672	F-14 CORROSION CONTROL	61 DAYS	VA-124 NAS MIRAMAR, CA	E2 and above	AMS OR AMH "A" SCHOOL OR EQUIVALENT
E-603-0571	SH-3 CORROSION CONTROL	54 DAYS	H-S-10 IMPERIAL BEACH, CA		AM "A" SCHOOL OR EQUIVALENT

As can be seen from the course titles, prerequisites and ratings trained, all existing training courses are designed and administered solely for the Aircraft Corrosion Control Program. While much of the curriculum matter is basic in nature and can be applied equally to GSE, the methods, processes, and materials for the prevention and control of corrosion deal almost exclusively with aluminum, the principal metal used in aircraft. GSE, constructed principally of carbon-steel and low alloy steels, require entirely different treatment.

As part of the overall solution to the GSE corrosion problem, a complete in depth survey of corrosion control training should be initiated. Curriculum content of the formal training courses listed in Table 8 as well as other possibly existing courses, should be closely examined and modified where necessary, to include instructional material pertinent to GSE corrosion control. Also, entry prerequisites should be expanded to include the Aviation

Ground Support Equipment (AV) rating and other personnel who may be assigned to corrosion control efforts on GSE.

The principal Navy document available for use as a guide to corrosion control in GSE is NAVAIR 01-1A-509, TECHNICAL MANUAL, AIRCRAFT WEAPONS SYSTEMS CLEANING AND CORROSION CONTROL, 1 JUNE 1975, see reference (8). That manual, while used successfully as a training test for squadron personnel to provide a background in the principles of corrosion and its prevention, is oriented towards aircraft corrosion control with only some mention of GSE. As previously stated, in GSE, the principal material is commercial grade steel plate that requires a totally different treatment than spelled out for aircraft that are fabricated principally of aluminum. The overall solution to the GSE corrosion problem must include the issuance of specific guidelines for the control of corrosion at all levels of maintenance.

6. Shipboard Conditions. The visit made to the CVA upon its return from the Mediterranean had as its purpose the accumulation of GSE corrosion data under what is believed to be the worst possible conditions. There, GSE is constantly exposed to salt air, stack exhaust gases, and high humidity conditions. Additionally, the tempo of operations subjects GSE to all forms of use and misuse. Wheel chocks, tie down chains, boarding ladders, and even tow bars are often indiscriminately thrown or placed on horizontal surfaces of GSE and the corrosion barrier is quickly destroyed. The MD-3 tow tractor with its gas turbine enclosure and the SD-1 spotting dolly are particularly susceptible to that type of abuse. On one MD-3 enclosure, the corrosion process had advanced to the perforated state and while that in itself did not render the unit inoperative, ship personnel stated that ingestion of particulate matter into the gas turbine had caused problems during the deployment. According to these same personnel, corrosion control activity was almost nil because of the demands placed on personnel just to keep the equipment in operation. They bitterly complained of the lack of space and time for adequate performance of corrosion control.

The severity of the shipboard GSE corrosion problem cannot be overstated. The conditions described above are considered typical for all common GSE operating in a shipboard environment. Design improvements and the application of more durable corrosion barrier schemes will lessen the severity of the shipboard corrosion attack; however, only a well organized, adequately staffed and trained GSE corrosion control organization involving all levels of maintenance will achieve the desired results.

7. Catastrophic Failures. No evidence of catastrophic failures of structural components of common GSE due to corrosion could be found during the fleet survey. When questioned on the subject, operating and maintenance personnel indicated that catastrophic failures on common GSE are usually limited to individual components rather than to structural members.

E. DESIGN CONSIDERATIONS.

1. Protection Against Corrosion. In the development of ground support equipment for Navy use, the design engineer must prescribe adequate measures for the protection of that equipment against corrosive attack. The details of each application are different, but the approach is the same: the design engineer must know the functional requirements of the design, the environ-

mental conditions which the item will most likely encounter in use, the metal alloys which are available, and the protective measures that can be employed.

In analyzing and correcting a potential corrosive situation, three steps are involved:

a. Considering the metal and ascertaining whether the choice is good or whether other metals might be better for the application.

b. Reviewing the design of the structure in which metals or other materials are to be employed and considering modifications which could alleviate the corrosion vulnerability, such as employing molded fiberglass components.

c. Providing the metal with a coating or treatment to protect it from the attacking medium. Improvement of GSE corrosion resistance in the order of nearly 2 to 1 over present coatings may be achieved through use of zinc-rich primers top coated with polyurethane paint. A revision of MIL-S-8512 and MIL-STD-808 specifying urethane coating systems as a procurement requirement as well as a design consideration should be instituted.

Even though the design engineer may be aware of the numerous aspects of a corrosive environment and can recommend appropriate protective measures, it is nevertheless difficult to achieve a design that satisfies all requirements. Metals or alloys which might possess higher resistance to corrosion might be unacceptable because of processing or economic factors. The design engineer may be forced to exchange some corrosion resistance for workability, mechanical properties, manufacturing considerations and availability or cost. In short, there are no strict rules for evaluating a design; the engineer must study the problem and be guided by the priority of the requirements.

2. Existing Design Deficiencies. Analysis of the pictorial record gathered in the course of this study revealed several deficiencies that merit special consideration at the design level. They are:

a. Moisture Entrapment. Remembering that moisture must be present for corrosion to occur, the elimination of all possible "sump" areas is vital. Where they cannot be eliminated adequately sized drain holes must be provided. Sharp corners, angles, pockets, or other conditions where solids or liquids could collect should be avoided where possible.

Wood, insulating materials or other substances which absorb or retain water should not be in contact with metallic surfaces. Butt welded joints should be used where possible, rather than riveted or spot welded lap joints. When lap joints are used, they should be selaed with solder, weld metal or sealant compound to prevent trapping of corrosive agents. Deck sheets and other top surfaces should be sloped to prevent water accumulation.

b. Access Plates and Doors. In an effort to provide easily maintained systems, design personnel have resorted to more and more access plates and doors to provide access to interior components. Based on the pictorial evidence gathered during the course of this study, it would be difficult to find an operational GSE unit that did not have at least one or

more broken, missing or malfunctioning door or access panel. Operator neglect, operational environment and in some cases, design shortcomings, all contribute to the virtually predictable destruction of these vital components. Installed to maintain the integrity of the unit, doors and access panels, once damaged, allow contaminants to enter into areas that are not readily available for cleaning and corrosion removal. Further, if not properly secured following use, they quickly become misaligned with their mating surfaces and fasteners become damaged and will not longer operate. Mobile electric power plants such as the NC-8A and NC-10B, with their large number of sensitive components, are particularly vulnerable once the exterior integrity of the unit has been broken.

Many of the access doors provided on GSE are fitted with piano hinges which are extremely vulnerable to fretting corrosion. Their use should be limited to those situations where alternate means of providing access cannot be provided.

c. Battery Compartments. Fumes from overheated electrolyte and spilled electrolyte are the most corrosive elements on ground support equipment. Every effort should be made to position batteries in an isolated location. If the battery is to be located within the interior of a unit, positive ventilation must be provided and special acid resistant materials should be used for the protection of the enclosure, support brackets and adjacent structural members.

d. Dissimilar Metals. Metals and alloys widely separated in the Galvanic Series (Table 1) must be avoided wherever possible. Where they must be joined, appropriate protective measures must be applied to prevent contact. Military Standard 889B, "DISSIMILAR METALS" defines and classifies dissimilar metals and establishes requirements for protecting coupled dissimilar metals. It should be included in all procurement specifications for ground support equipment.

Dissimilar metal contact is most critical in those areas where fasteners (bolts, screws, rivets, etc.) are installed. The major portion of all corrosion incidents originate in these highly vulnerable locations. Wherever possible, fasteners should be avoided. Where they must be used, maximum protective measures as specified in MIL-STD-889B should be employed.

F. SELECTION OF PROTECTIVE COATINGS. Coating systems as they have been specified by design engineers and applied by the manufacturer in the past have proven to be largely ineffective. The requirement to seek and apply alternative methods to protect ground support equipment against corrosion resulting from protective coating failure and/or operational damage must be a prime consideration if there is to be an improvement in the corrosion picture.

1. Types of Protective Coatings. Coating systems for metals used on ground support equipment can be divided into three classes: (1) chemical and electrochemical coatings; (2) metal coatings; and (3) organic coatings. The first two categories are used primarily to provide initial corrosion protection and/or wear resistance of metals at manufacture, or at depot level facilities during equipment rework cycles. Discussion herein on chemical, electrochemical, and metal platings is limited to that required

for a basic understanding of the processes and their application. It is important, however, for the design engineer to be aware of the special protection requirements of various components of ground support equipment and their corrosion and wear vulnerability. Thus informed, and when economically feasible, optimum protection schemes should be individually specified.

a. Chemical and Electrochemical Coatings. Chemical coatings can be formed on steel, iron, aluminum, magnesium, cadmium zinc and other metals and alloys. The chemical treatments are usually applied by a dipping process where possible or by spraying. Dependent on the circumstances under which they are applied, chemical coatings, while offering little abrasion resistance, are self-healing when scratched and significantly improve the adherence of subsequent coatings.

Electrochemical coatings, also known as anodic coatings, are chemical conversion coatings applied by electrolysis. The type of coating used is determined by the type of base metal to which it is applied. Anodic oxide coatings are more expensive than other chemical treatments; however, they offer optimum protection to aluminum and magnesium.

Table 9 contains the principal characteristics of the chemical and electrochemical coatings now in use. Applicable military specifications are included for further reference.

b. Metal Plating. Metal plating coatings are used extensively to protect base metals. In the electroplating process, the metal that is to be protected is made the cathode, while the plating deposit is usually made the anode. This is accomplished by applying direct electric current through the metal for a predetermined period of time. The metals commonly considered as electroplates are zinc, cadmium, chromium, copper, lead, nickel, tin, gold and silver.

Metal platings that are anodic will protect the base metals by sacrificial action, while cathodic coatings will accelerate the corrosion of the base metal if it is exposed. For that reason, electrodeposited coatings are generally selected based on their inherent corrosion resistance and as to whether they are anodic or cathodic to the base metal. It is not always possible for the plating to be anodic to the base metal. For example, any metal plating that might be applied to magnesium is cathodic to it according to the galvanic series. (See Table 1.) Also, excepting zinc, all other metal platings are cathodic to aluminum. Despite these apparent shortcomings, they can be used to narrow the potential differences of the metal couples. Table 10 lists the commonly used electroplatings, their applications, characteristics and applicable military specifications.

c. Organic Coatings. Regarding corrosion control on ground support equipment in the Navy, the third type of protective coatings, organic coatings, is of primary importance. The evidence gathered in the course of this investigation has made it abundantly clear that only the most durable and corrosion resistant final coating systems are capable of performing satisfactorily in the severe Navy Operating environment. Table 11 describes the available paint systems in their order of effectiveness for the protection of exposed surfaces of GSE.

Table 9. CHEMICAL AND ELECTROCHEMICAL CONVERSION COATINGS

CHEMICAL

TYPE COATING	FOR USE ON	APPLICABLE MIL SPECS	CHARACTERISTICS
Phosphate	Steel, Zinc, Cadmium, Aluminum and Their Alloys	MIL-P-16232D TT-C-490B MIL-P-5002A	1. Increased Paint Adherence. 2. Applied by immersion or spray. 3. Not suitable for parts having a hardness of Rockwell C48 or higher. 4. Provides corrosion protection.
Chromate	Aluminum, Zinc, Cadmium, Beryllium	MIL-C-81706 MIL-C-5541 MIL-T-12879 MIL-C-17711 MIL-C-81562 QQ-Z-325 ZZ-P-416	1. Used extensively on military equipment. 2. Increases paint adherence. 3. Provides corrosion protection. 4. Adversely affected when exposed to high heat. 5. Can replace anodizing in some applications.
Oxides	Steel, Stainless Steels, Copper	MIL-C-13924B MIL-F-494A	1. Limited use on GSE. 2. Process is intended to blacken metal, thereby reducing reflectivity.

ELECTRO-CHEMICAL

Anodic	Cast or wrought aluminum, Magnesium and Zinc Alloys. Titanium Beryllium	MIL-M-45202 MIL-A-81801	1. Harder, thicker and more corrosion and abrasive resistant than chemical treatments above. 2. Excellent bases for subsequent coatings. 3. Lacks elasticity. Will form fissures if substrate metal is stressed.

Table 10. METAL PLATINGS, ELECTRODEPOSITED

PLATING	APPLICATION	APPLICABLE MIL SPECS	CHARACTERISTICS
Cadmium and Zinc	Steel, Iron	QQ-P-416 QQ-Z-325	1. Improves corrosion resistance on ferrous metals. 2. Inexpensive
Chromium	Various (see applicable MIL Spec)	QQ-C-320	1. Highly corrosion resistant if coating remains intact. 2. Usually applied over coats of copper and nickel. 3. Used primarily for wear resistance.
Copper	Various (see applicable MIL Spec)	MIL-C-14550	1. Used to plate aluminum to permit soldering. 2. Not used as protective coating by itself. 3. Undercoat for nickel and chromium plates on steel and zinc alloy.
Lead		MIL-L-13808	1. Used to protect copper, brass, or steel from sulfuric acid. 2. Acid container liners.
Nickel	Steel, Aluminum, Brass, Copper, Zinc and others	QQ-N-290 MIL-C-26074	1. Most commonly used plating over steel for corrosion protection. 2. Usually overplated with chromium. 3. Can be applied without use of electricity.
Tin	Steel, Copper, Aluminum	MIL-T-10727	1. Can be used to reduce friction on aluminum. 2. Very little application on GSE. 3. Can be applied by "hot dip" method.
Gold & Silver		MIL-G-45204 QQ-S-365	1. Used in highly specialized applications only. Electrical contact, tarnish resistance, etc.

Table 11. ORGANIC PAINT SYSTEMS

SYSTEM	SURFACE PRETREATMENT	PRIMER COATING	APPLY IN ACCORDANCE WITH	RECOMMENDED APPLICATION	REMARKS
Polyurethane MIL-C-81773	Wash Primer MIL-C-8514	Epoxy Primer MIL-P-23377	MIL-C-81907	For all exposed surfaces on GSE that are to be exposed to the elements.	Acrylic lacquer can be used for touch up purposes at local levels where safety restrictions preclude use of polyurethane.
Epoxy MIL-C-22750 Class 1 Class 2	Wash Primer MIL-C-8514	Epoxy Primer MIL-P-23377 Class 1 Class 2	MIL-C-22751	For all exposed surfaces on GSE that are to be exposed to the elements.	Touch up can be accomplished using same materials as original top coat. Epoxy systems are essentially as durable as polyurethane systems. However epoxy systems tend to become chalky when exposed to elevated temperatures. Class 1 intended to be used over Class 1 primer. Do not mix classes.
Lacquer, Acrylic MIL-L-81352	Wash Primer MIL-C-8514	Epoxy Primer MIL-P-23377	MIL-F-18264	For touch up applications over polyurethane system at local level.	Can be used as a marking lacquer directly over freshly applied epoxy top coat. A top coat of epoxy primer is necessary over polyurethane top coat before application of acrylic lacquer.
Enamel, Alkyd	Wash Primer MIL-C-8514	Primer Alkyd TT-P-636 TT-P-645		Can be used on GSE that will will not normally be exposed to the elements.	

NOTE: Paint systems listed in order of effectiveness and durability.

The current practice is to specify Military Standard 808, "Finishes, Protective, and Codes, For Finishing Schemes For Ground Support Equipment" as the guiding document for the application of coating systems. That document, written for the Air Force in 1957, does not, in all cases, reflect the latest state-of-the-art in regard to corrosion control. Its use, particularly as it applies to final coating systems on ferrous metals, should be discontinued. It should be noted that the Air Force, operating in a far less hostile corrosion environment, has long ago abandoned the wide-spread use of Military Standard 808, reference (9).

Military Standard 808 specifies the use of alkyd enamel over a primer coating for exterior surfaces of ground support equipment constructed of ferrous alloys. Unexposed surfaces receive only a primer coating. While those systems afford adequate protection on equipment that is used primarily in sheltered areas, their use on flight line and shipboard equipment is questionable in view of the availability of the far more durable and long-lasting epoxy and polyurethane paint systems.

(1) Epoxies and Polyurethanes. Despite the many advantages to be gained from the use of epoxies and polyurethane systems, there is a general reluctance in the Navy to effect the changeover. Investigation shows that the opposition is focused on two general areas:

(a) Because of their toxic properties, the use of epoxy and polyurethane paint systems at the organizational and intermediate levels of maintenance is highly restricted. Thus, the reasoning is that if it cannot be repaired at field activities, *it should not be applied in the first place.*

(b) Epoxy and polyurethane systems are difficult to remove during repaint operations.

Considering the conditions and limitations of existing corrosion control facilities at most organizational and intermediate level activities, the OSHA restrictions governing the use of epoxy and polyurethane systems are considered valid. Application of those systems to ground support equipment is recommended procedure at all installations where equipment is adequate to meet OSHA safeguards. At installations where OSHA requirements cannot be met for covering areas using a large volume of paint, preventive maintenance touch-up operations can be satisfactorily performed providing precautions of NAVAIR 00-85A-503, COATING MATERIALS FOR AIRCRAFT USE, SAFETY PRECAUTIONS, No. 2 are adhered to, reference (10). Toxicity of epoxy-polyamide systems are less than that of urethane systems and polyamides may be used as a not quite so satisfactory substitute where safety requirements preclude use of urethane. Otherwise use the much safer but less durable enamels and lacquers indicated in Table 11.

The fact that epoxy and polyurethane systems are difficult to strip mechanically merely attests to their superior adhering qualities. The opposition to their use in this regard can only stem from the current practice of complete repainting of GSE units at the intermediate level of maintenance vice preventive maintenance touch-ups.

In two separate meetings held with personnel of the Materials Section of the Naval Air Development Center at Warminster, Pa., the use of

epoxy and polyurethane systems on ground support equipment was strongly recommended. Also, the Air Force, heavily committed to the battle against corrosion on ground support equipment, has fully transitioned to the polyurethane systems for equipment that is exposed to the elements with the issuance of Technical Order 35-1-3 on 15 November 1976, reference (11).

Tests conducted in 1970 and 1972 by the Materials Engineering Division of the Naval Air Rework Facility at Alameda, California, appear to offer the most significant testimony in favor of the use of polyurethane paint systems on GSE that is subjected to marine atmosphere, reference (12).

Initiated primarily to evaluate the performance of zinch-rich primers, the tests also included the application of various top coat materials for the protection of the primers. The results, included in their entirety in Appendix B clearly show the superior adherence and abrasion resistant qualities of the polyurethane paint systems in a severe operational and corrosion producing atmosphere.

The tests included the application of various commonly used top coats overcoatings of zinc-rich primers. The coatings were applied to 5 MD-3 tow tractors and placed into service aboard the USS Oriskany prior to a nine month deployment in the Pacific.

As a result of those tests it was concluded that: "The best-performing zinc-rich primer in combination with the polyurethane topcoat can substantially upgrade the corrosion protection of ferrous GSE and, in addition, provide a very meaningful reduction in maintenance costs of GSE at the fleet level and at overhaul."

In its recommendations the report stated: "In view of the findings of this investigation, it is recommended that a zinc-rich primer and a polyurethane topcoat paint system be utilized as the preferred finish system on MD-3 tractors." "It is further recommended that a zinc-rich primer and polyurethane top coat paint be used on most carrier equipment, such as spotting dollies, forklifts, NC-2A mobile electric power plants and other ferrous based equipment."

In view of the above, it can only be concluded that the transition to polyurethane paint systems offers the potential for significant reductions in the number of maintenance manhours now being expended to maintain the corrosion barriers on ground support equipment. However, because the use of polyurethanes represent a somewhat radical departure from current accepted practices in the eyes of many operating personnel, the transition to polyurethanes must necessarily be approached with caution. Technical directives and guidelines for the use and maintenance of polyurethane paint systems should be developed and issued for use at the various levels of maintenance prior to the initiation of widespread use of polyurethanes. In that regard, the GSE Corrosion Control Manual now being considered for development and issuance by the Naval Air Systems Command could, if approved, serve as the vehicle to achieve that purpose.

G. SPECIALIZED PROTECTIVE COATINGS. In the past several years, significant advances have been made in the development of inorganic protective coatings for metals. Several of these products appear to have significant potential

for use on ground support equipment components and structural surfaces. The application process involving these highly durable materials is usually complex and normally requires special equipment and/or facilities. For those reasons, their use on GSE must be thought of in terms of application at manufacture or depot level facilities only. One of the products, NYLON-11, is currently undergoing operation evaluation at the Naval Air Development Center at Warminster, Pa. While the product is proving to be extremely wear and abrasive resistant, some problems are being encountered in developing methods to affect minor repairs to the system once it becomes damaged. Table 12 summarizes those products for which literature has been obtained and limited study to determine possible applicability to GSE has been made.

The listing is intended as a representative sampling of available products and the information contained therein is based solely on manufacturer claims.

There exists the possibility that some of the products listed or some with similar properties are in fact being used at local levels of maintenance in the Navy. Interviews with operating personnel during the fleet survey revealed that, in their efforts to lessen the corrosion burden, the more enterprising of these personnel often resorted to commercially procured products.

Generally, these products are more expensive than the conventional coatings; however, their high initial cost is quickly offset by the savings generated through longer intervals between paintings and the resulting reduction in maintenance manhours.

In view of the significant savings potential offered by these specialized coatings, test and operational evaluation programs should be initiated to determine their applicability to ground support equipment.

H. CORROSION CONTROL EQUIPMENT AND MATERIALS. Appendix A contains a listing of materials and equipment currently available in the Navy for use in corrosion control efforts.

Virtually all of the listed specialized equipments have been developed and procured for use primarily in the aircraft corrosion control program which now accounts for approximately 90% of its use. The listing includes high pressure cleaning machines, corrosion removal equipment and the materials associated therewith. Chemical paint stripping compounds are also included.

1. High Pressure Cleaning Machines. The degree of success achieved in any corrosion control program relies heavily on the ability to effectively remove corrosion producing contaminants from all surfaces of the material that is being protected. High pressure cleaning machines are at present used for that purpose.

Items 1 through 4 of Appendix A are the most common of the high pressure cleaning machines now available for the cleaning of aircraft and ground support equipment. Unfortunately, the limited number of these equipments available to individual Commands as well as frequent mechanical failures (stated by operating personnel) normally dictates that their use

Table 12. SPECIALIZED PROTECTIVE COATINGS

PRODUCT	DESCRIPTION	APPLICATION PROCESS	CURING TIME AND TEMPERATURE	REMARKS
NYLON II (DUPONT)	Nylon Powder	Electrostatically applied over wire sprayed aluminum or over epoxy primer.	Cured by placing in oven and raising temperature to 400°. No specific time.	Currently undergoing OPEVAL at NADC.
ALSEAL-500 (COATINGS FOR INDUSTRY INC.)	Aluminum Powder in an organic - inorganic binder	Spray gun. Material is furnished ready for use.	Minimum: 250°F for 30 minutes Maximum Protection: 1025°F for 60 minutes	Water clean-up of spray equipment.
SERMETEL "W" (SERMETEL INC.)	Inorganic water based aluminum powder.	Brush, spray, dipping, rolling. Spray preferred.	Varying dependent on class.	Available in 4 classes. Classes determined by degree of postcuring or surface alteration to the cured coating.
URETHABOND 107 (COATINGS FOR INDUSTRY INC.)	Single component aluminum filled moisture curing urethane. Can be applied directly to rusted surface.	Brush, roll or spray.	Drying time @ 75°F. 50% relative humidity: Tack Free - 1.25 hrs. Hard Dry - 3.0 hrs. Mar Free - 4.5 hrs.	Topcoated with urethabond/U-100 for severe corrosion environment.
URETHABOND/U-100 (COATINGS FOR INDUSTRY INC.)	Single component	Brush, roll or spray.	Same as Urethabond 107 above.	Used as a topcoat over Urethabond-107 in severe corrosive environment.
PERMATHANE RUSTITE (MFG ASSOCIATES)	Single component, fast curing, urethane system.	Brush, roll or spray.	Not stated. Approximately same as Urethabond 107 and U-100.	

be limited to corrosion control efforts in the highly visible aircraft corrosion control program.

While equipment shortcomings are not entirely blameless, the two underlying reasons for the frequent failures of pressure cleaning machines when used on ground support equipment, regardless of the procurement source, usually are: (1) unfamiliarity with operating procedures and/or (2) neglect of required preventive maintenance. Both reasons appear to stem from the relatively low priority assigned to corrosion control on GSE and a lack of sufficient numbers of trained personnel.

In their normal configuration these machines are trailer mounted and capable of producing water and detergent solutions under pressure (500 to 700 PSI). Following an arbitrary working time, the solution is then rinsed away with plain water. Some of the units incorporate water heaters to enhance the cleaning process.

In this same family of cleaning machines is the foam-producing equipment described in Military Specification MIL-C-81762 (Item 5, Appendix A). Small and generally uncomplicated, it affords an economical means of mixing air, water, and cleaning compounds to form a foam capable of clinging to vertical surfaces long enough to soften and dislodge adhering soils.

Because of electrical shock encountered through the use of water as a cleaning solution vehicle, naval personnel at some commands have discontinued use of (Item 5, Appendix A) electrically powered pressure cleaning equipment. In response to requests for equipment using non-conductive foam solutions GSERD's have been written for waterless foam generators in 20 gallon and 60 gallon capacities, the 20 gallon to be a shipboard item and the 60 gallon for land based use. (See Figure 7.) These units require no electrical power but operate on 100 to 150 PSI air.

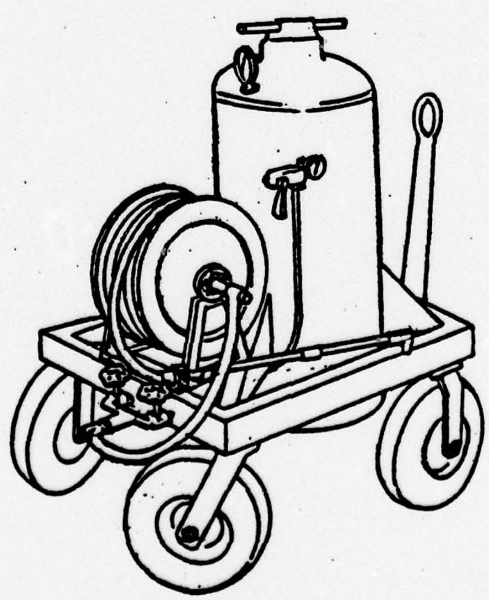

Figure 7. MODEL 60 B&B JET BLAST PORTAFOAMER FOAM DISPENSING MACHINE

Other than the units now available in the Navy Supply System, several other models and types that appear to be suited for application in a ground support equipment corrosion control program were identified in the course of this investigation. Table 13 is a listing of those units for which limited investigations to determine applicability have been made. In view of the anticipated large scale use of high pressure cleaning machines in the GSE corrosion control program, further investigation of these units is warranted. This investigation should determine: (1) the adequacy of in-use high pressure cleaning machines in terms of their applicability to widespread use on ground support equipment and (2) if this equipment represents the most economical, durable, and easy-to-maintain systems available.

Table 13. CLEANING MACHINES

MANUFACTURER	MODEL	OPERATING PRESSURE(S) PSI
F. E. Myers & Bros.	MC30-12M MC10-12M MC10-12E	200 - 1200 200 - 1200 200 - 1200
Hydro Systems	Hydro-Blitz 710	700
Homestead Industries Jenny Division	E-350C	400
Fieldway Industries	538	750+
The Kent Company	KW-102	500

2. Corrosion and Paint Removal Equipment. Due largely to the current practice of conducting complete repainting operations at the organizational and intermediate levels of maintenance, the universal appeal heard during the fleet tour was for equipment that would facilitate the burdensome task of paint and corrosion removal. At many sites, in an effort to ease the burden, various equipments, touted by local vendors as the panacea of paint and rust removal, have been procured. These equipments, while usually effective in varying degrees during initial service, quickly become victims of inadequate spare parts support. The result is that most activities quickly lose confidence in the reliability of the equipment and abandon their use.

At the intermediate and organizational levels of maintenance, wire brushes, sandpaper, disc sanders, and flap brushes are the usual tools being used for the removal of corrosion and paint from ground support equipment. Chemical paint strippers, because of safety considerations, are in very limited use.

a. Disc Sanding. While disc sanding does a reasonably good job on large flat surfaces, its effectiveness is often hampered by angles, curved surfaces, nuts, bolts, fasteners, etc. In those instances, the thoroughness of the corrosion removal effort becomes totally dependent on the determination and patience of the individual assigned to the task. A needle scaler, (Item 7, Appendix A) capable of removing rust, scale, paint etc. from hard

to reach surfaces, was found to be available in the supply system; however, evidence of its use during the fleet tour could not be found.

b. Chemical Paint Stripping. The use of chemical paint strippers to ready equipment for painting was found to be in very limited use at other than depot level facilities. This was due largely to the many safety considerations involved when using these highly toxic products.

Extreme care must be taken in readying GSE for chemical stripping operations. Extensive masking is required to prevent the chemicals from contacting vulnerable seals, glass, plastics etc. Also, in the process of applying and rinsing off of the chemicals, personnel safety hazards must be considered. As an example, mist generated from the rinsing process can cause burns on exposed skin. Operators might have to be fully protected from that danger as well as having to be outfitted with breathing apparatus.

Because of the many inherent hazards of chemical stripping compounds, their use must be limited to those activities where adequate facilities are available.

c. Ultra High Pressure Machines. The use of ultra high pressure (10,000 to 20,000 PSI) water borne particulate to strip away paint and corrosion products from metal substrates is receiving increasing interest in the industrial and military communities. One of these, the Hydroblaster, Model 610-E (see Figure 8) is currently undergoing operational testing and evaluation at selected sites under the sponsorship of NAVAIR. As the high operating pressure suggests, there are many attendant safety considerations and its use must be under strictly controlled conditions. Initial indications appear favorable and if approved for service use, it is expected that the distribution of the units will be limited to those activities with a high concentration of ground support equipment and capable of providing the required safe operational environment.

Other systems, designed to operate in the 2,000 to 20,000 PSI range have been developed and appear to offer significant potential for corrosion removal and paint stripping operations at the intermediate and depot levels of maintenance. Further investigation with a view towards possible operational evaluation appears warranted and is recommended. Table 14 below is a listing of those equipments for which literature has been obtained and limited investigation to determine applicability has been made.

Table 14. ULTRA HIGH PRESSURE CORROSION AND PAINT REMOVAL EQUIPMENT

MANUFACTURER	MODEL	OPERATING PRESSURE(S) PSI
Partek Corporation	Various	2,000 - 10,000
Aqua Dyne Systems	Various	3,000 - 20,000
Parkside Systems Inc.	1020-G 1020-E	2,000 2,000
Hydroblaster (NOTE)	610-E	10,000

NOTE - Currently undergoing OPEVAL.

Figure 8. HYDROBLASTER MODEL 610-E

VI. CONCLUSIONS

A. Conclusions reached as a result of this study are as follows:

1. The corrosion problem on Navy ground support equipment is considered to be Navywide and encompasses virtually all types and models of GSE. The principal causes of corrosion on GSE are (1) the inability of the in-use corrosion protection schemes to withstand the severe environment in which the equipment is stored and operated; (2) a lack of well organized, aggressively applied preventive maintenance programs at the various levels of GSE maintenance.

2. The prevailing corrosion control programs in Naval Aviation emphasize the prevention and control of corrosion on aircraft, presumably because of their relative higher value and limitations on numbers of available corrosion control personnel. This philosophy relegates GSE to the bottom of the priority ladder for both equipment and personnel. It also serves to de-emphasize the various necessary elements to effectively combat corrosion on GSE. For instance, Navy Training Courses and Technical Manuals on the subject of corrosion control are designed almost exclusively as tools for combatting corrosion on aircraft. GSE, constructed principally of ferrous metals and alloys require different methods, materials and procedures.

3. Actual dollar costs can be approximated even though 3M data contains inaccuracies in maintenance data reporting. Analysis of 3M data contained in the Maintenance Data Collection System (MDCS) indicate manhours expended in maintenance of in-use paint systems represents the bulk of expenditures for GSE corrosion (approximately 80% of the 3M annual cost). Efforts to achieve dollar savings must therefore concentrate on increasing the service life of GSE corrosion barrier schemes. The specifying of polyurethane paint systems as the final barrier coating and the elimination of design deficiencies that promote corrosion situations, offer significant potential for achieving these dollar savings.

4. The problems of corrosion on electronic and electrical components of GSE, although emanating from the same causes, require entirely different considerations for treatment and repair. Two recent Navy studies, references (3) and (4), have resulted in the development of a corrosion control manual dedicated solely to the treatment of corrosion on Avionics components. One chapter of a forthcoming manual for Control of Corrosion in Ground Support Equipment will be devoted to corrosion treatment of electronic and electrical components installed on GSE.

5. The Maintenance Data Collection System as it currently collects data on corrosion related maintenance actions is less than optimal. Because of the broad range of "Malfunction Description Codes" available for use by reporting custodians of GSE, it appears that many corrosion related failures are being masked under such codes as 070 - "BROKEN", 615 - "SHORTED" etc. The reasons for the less than accurate reporting are believed to be (1) operationally imposed expediency in completing the "paper work"; and/or (2) because of inadequate training in the detection of corrosion situations.

6. Several new products, emerging from the intensive research and development programs now underway in the scientific, industrial and military

communities on the subject of corrosion and its control, appear to be suitable for GSE applications. A need exists to develop ways and means of evaluating these new products, as they become available, for possible long term economic benefit.

7. Geographic location, initially viewed as important in the overall solution to the GSE corrosion problem, was found to be an insignificant factor in the selection of corrosion barrier schemes to be applied to GSE. Because of continuing and unpredictable changes in operational needs, equipments are often shifted to many locations during their service lives. Also, inasmuch as Navy GSE must operate primarily in hostile near-ocean environments, only the most durable of the available barrier schemes will perform satisfactorily. Geographic location does, however, remain an important consideration in the development of local preventive maintenance programs.

VII. RECOMMENDATIONS

A. The problem of corrosion on ground support equipment encompasses, in varying degrees, all segments of the GSE design, procurement and maintenance. Like all problems that have long been ignored or tolerated, improvements and ultimate solutions are not simple. There are no "one shot" solutions available. Rather, the problem can only be solved through conscientiously applied individual actions, implemented only after careful consideration of all factors involved.

1. An increased awareness of the corrosion problem must be fostered and maintained at the design level. Where practical and economically feasible only the most durable corrosion barrier schemes should be specified. In that respect, design personnel must be kept fully aware of the new advances being made and the new products now available for use in the battle against corrosion. New designs should be carefully screened to assure the elimination of all possible corrosion producing situations such as the coupling of dissimilar metals and moisture entrapment areas. Batteries should be isolated wherever possible. Where isolation is not possible, special protective measures should be employed on the surrounding areas. Access doors and plates should be eliminated wherever possible.

2. The specifying of Military Standard 808 as the guiding document for protective finishes on ground support equipment that is to be exposed to the elements should be discontinued. Individual specifications that represent the latest "state-of-the-art" and provide the most practical and economical protection should be used in the procurement of new equipment. Epoxy and urethane paint systems should be specified as the final coating systems in all future procurements as well as on all ground support equipment inducted into depot level rework activities. MIL-STD-808 and specification MIL-S-8512 should both be revised to specify epoxy and urethane paint systems as a procurement requirement or they should be replaced with a new standard and specification.

3. Open skies storage, the norm for GSE at most Navy activities, is considered one of the principal contributors to the initiation and acceleration of the corrosion process on GSE. While not within the scope of this study for detailed analysis, it appears that significant gains in the battle against corrosion could be achieved if the practice of storing GSE under open skies could be eliminated or reduced. It is recommended that local base commanders initiate surveys of individual activities to identify and make available indoor or under roof storage areas for GSE where possible.

4. GSE corrosion control programs, as presently organized, are for the most part ineffective. The reasons for the program shortcomings, discussed in detail in the text of this report, center primarily on a lack of adequately trained personnel and the absence of specific operational guidelines. Established Formal Training Courses as well as available technical manuals on the subject of corrosion are structured almost entirely as tools to combat corrosion on Navy aircraft. There is little or no mention of GSE corrosion control procedures. Accordingly, the following corrective measures are strongly recommended:

a. The curriculum content of existing Formal Training Courses on the subject of corrosion control should be expanded as necessary to include corrosion control procedures for GSE. Entry prerequisites should also be reviewed to ensure attendance at the schools by those Navy ratings charged with corrosion control responsibilities on GSE.

b. Specific directives and guidelines for the detection and treatment of corrosion at the local levels of maintenance should be prepared and issued as soon as practical. The proposed GSE corrosion control manual, now under consideration for development and publication by the Naval Air Systems Command should be developed as quickly as possible.

5. As a result of intensive research now underway in the industrial, military and scientific communities, several new corrosion inhibiting products have been or are being developed. Several of these products appear to offer significant potential for long term dollar savings in terms of extended equipment service life and a reduction in maintenance manhours. Limited investigation of some of these products has been made to determine applicability to GSE. The products investigated are contained in Tables 12, 13 and 14. A need exists to establish procedures for the continuing evaluation of newly developed corrosion control products in order to determine their possible economic benefits when applied to GSE. Programs to extensively evaluate these and other products for suitability of application to GSE are recommended. These programs would provide service life data, establish a life cycle cost basis and generate data to determine if cost reductions may be achieved by use of the products on GSE.

6. The ability to closely monitor recurring corrosive problems during the life cycle of GSE, as well as the initiation of corrective measures, relies heavily on the information reported by field activities and recorded in the Maintenance Data Collection System. Because of the broadness of the "Malfunction Description Codes" used to report maintenance actions, corrosion related failures are often reported erroneously under such codes as 070 - "BROKEN" or 615 - "SHORTED" etc. While increased training in detection procedures will tend to lessen this problem, appropriate administrative action stressing the importance of accurate corrosion 3M reporting is warranted.

VIII. REFERENCES

(1) NAEC-GSED-91, Control of Corrosion in Ground Support Equipment, Interim Report, June 1975

(2) NAEC-GSED-106, Control of Corrosion in Ground Support Equipment, Interim Report, September 1976

(3) "Naval Aircraft Avionics Corrosion Prevention and Control," Final Report, Phase 1, by L. W. Grzech and R. C. Schrei to Service Life Programs Office, Naval Air Development Center, January 1974

(4) "Avionics Corrosion Control Study," Final Report by Bendix Field Engineering Corporation to Analytical Rework/Service Life Programs Office, Naval Air Development Center, January 1974

(5) NAEC-GSED 92A3, GSE Retirement Program Inventory Summary, July 1977

(6) "The Naval Aviation Maintenance Program, Chief of Naval Operations Instruction 4790.2A

(7) "Catalogue of Navy Training Courses" July 1977

(8) NAVAIR 01-1A-509, Technical Manual, Aircraft Weapons Systems Cleaning and Corrosion Control, Organizational and Intermediate, 1 June 1975, Change 1-15, January 1976

(9) Military Standard 808, Finishes, Protective, and Codes, For Finishing Schemes for Ground and Ground Support Equipment, 5 February 1957 (USAF)

(10) NAVAIR 00-85A-503, Coating Materials for Naval Aircraft Use, 1 April 1973

(11) Air Force Technical Manual, "Corrosion Prevention, Painting and Marking of USAF Support Equipment (SE), F41608-75-D-A245, 15 November 1976 (TO 35-1-3)

(12) Materials Lab Test Report, "Zinc-rich Primer Systems on MD-3 Tractors; Evaluation of," NARF, NAS, Alameda, NARF-343-JRL/Sh 372-17

APPENDIX A. CORROSION CONTROL EQUIPMENT AND MATERIALS

ITEM	NOMENCLATURE	APPLICABLE SPECIFICATION	STOCK NUMBER	LEVEL OF MAINTENANCE	DESCRIPTION AND USE
	CLEANING MACHINES				
1.	High Pressure Cleaning Machine Mod: 328500 Mfr: Stewart-Warner		6RX-4920-00-986-0809-5X	All	Mobile, trailer mounted, air driven (40 to 125 PSI) aircraft cleaning machines.
2.	High Pressure Cleaning Machine Mod: 616710 Mfr: Aro Equip. Corp.		6RX-4920-00-788-1144-5X	All	Used to apply and rinse away solutions of water and cleaning compounds. (MIL-C-25769 and MIL-C-43616)
3.	Cleaning Machine, Aircraft, Mobile Mod: 907201-1 Mfr: Henry Spencer		6RX-4940-00-782-1630-SX	All	
4.	Cleaning Machine, Aircraft, Mobile Mod: 520/500 NTM Mfr: Sioux Corp.		4920-00-503-5261	All	
5.	L&A Pressure Washer Portable, Electric Mod: 782N Mfr: L&A Products Inc.		4940-00-137-9841	All	
6.	Cleaner, Pressure Water, Foaming	MIL-C-81762	1R4940-00-152-2028-SX	"O" and "I"	Small economical unit for mixing air, water and detergent into foam capable of clinging to vertical surfaces
7.	Needle Gun, Pneumatic		5130-00-585-6491	"O" and "I"	Removal of heavy corrosion deposits and paint from irregular surfaces and areas not readily accessible.
8.	Disc Sander, Pneumatic, Electrical		5130-00-203-4856 5130-00-203-4857	"O" and "I"	Removal of paint and heavy corrosion from level, readily accessible surfaces.
9.	Air Drill Motor, 1/4" chuck, 3200 RPM		9Q5130-00-294-9511	"O" and "I"	For use with flap brush, Item 13.
	CORROSION REMOVAL MATERIALS				
10.	Aluminum Wool	MIL-A-4864 Type II	5350-00-286-4851	All	To remove light corrosion deposits from aluminum.
11.	Sand Paper, Aluminum Oxide: Very Fine 320 Grit Fine (150) Med. (100) Med. (80) Coarse (60) Coarse (50) Assortment 72 sheets 4-1/2" x 5-1/2"	P-C-451	5350-00-246-0330 5350-00-187-6289 5350-00-192-5050 5350-00-161-9066 5350-00-192-5047 5350-00-253-4393 5350-00-246-0333 5350-00-271-5950	All	To remove light to medium corrosion products.
12.	Abrasive Mats, Non Woven, Non Metallic	MIL-A-9962	9Q5350-00-967-5089(V. Fine) 9Q5350-00-967-5093 (Fine)	All	Aluminum oxide impregnated webbing used for removal of corrosion products; paint scuffing and feathering.
13.	Flap Brush, Non Woven, Non Metallic		9Q7920-00-151-7936 (Fine) 9Q7920-00-157-9790 (Med.)	"O" and "I"	Removal of mild surface corrosion; mechanical removal and feathering of paint.
14.	Wheel, Abrasive	MIL-W-81319 Class 2 Type I	9Q5345-00-732-9978		Removal of heavy corrosion deposits.
15.	Abrasive Disc: Coarse Medium Fine	RD-455	5435-00-194-6079 5435-00-194-6065 5435-00-194-6082	"O" and "I"	For use with Item #8 in the removal of paint and heavy corrosion deposits.
16.	Dry Cleaning Solvent	P-D-680 Type II	9G6850-00-274-5421	"O" and "I"	General purpose cleaning solvent for removal of oil, grease and preserving compounds.
17.	Cleaning Compound, Alkaline, Waterbase	MIL-C-25769	9G6850-00-935-0996(5 gal)	"O" and "I"	Removal of light, non oily, dry soil. Can be used with cleaning machines Items 1 through 4.

APPENDIX A. CORROSION CONTROL EQUIPMENT AND MATERIALS (CONT'D)

ITEM	NOMENCLATURE	APPLICABLE SPECIFICATION	STOCK NUMBER	LEVEL OF MAINTENANCE	DESCRIPTION AND USE
18.	Cleaning Compound Aircraft Surface	MIL-C-43616 Class I Class 1A (Aerosol	9G-6850-00-180-5943(5 gal) 9G-6850-00-180-5946(16 gal) 9G-6850-00-180-5945(55 gal) 9G-6850-00-005-5305(16 oz)	"O" and "I"	General purpose cleaning compound for removal of soils from metal surfaces, suitable for use with cleaning machines Items 1 through 4.
19.	Sodium Bicarbonate	O-S-576	9G-6810-00-264-6618	All	Used to neutralize acid spills and electrolyte deposits in battery compartments.
20.	Detergent, Water Solvent	MIL-D-16791 Type I	7930-00-985-6911	"O" and "I"	General purpose cleaning of exposed exterior surfaces.
21.	Cloth, Cleaning, Non-woven fabric	CCC-C-46 Class 4	9Q7920-00-292-9204	"O" and "I"	For wiping machines areas actuating rods etc.
22.	Cleaning Pad, Non-metallic	MIL-C-83957	9Q7920-00-151-6120	"O" and "I"	Hand cleaning of metal surfaces
23.	Pads, Scouring	L-P-50 Type V	9Q7920-00-753-5150	"O" and "I"	To remove stubborn stains and mild corrosion.
	CHEMICAL PAINT STRIPPING COMPOUNDS				
24.	Remover, Paint and Lacquer, Solvent Type	TT-R-248			For stripping lacquer and enamel coating systems from metal surfaces.
25.	Remover, Paint Epoxy System	MIL-R-81294	9Q-8010-00-926-1489(55 gal) 9Q-8010-00-926-1488(5 gal) 9Q-8010-00-181-7568(1 gal)	"I" and "D"	For stripping epoxy paint systems from metal surfaces.

APPENDIX B. PHOTOGRAPHS OF GSE CORROSION

Appendix B consists of selected representative photographs of GSE corrosion conditions encountered at NAS, MCAS, NARF and FLEET between east and west coast facilities. These photographs, chosen from over seven hundred photographs, show the various types of corrosion conditions and their effects on GSE.

The following list of forty-two photographs are presented:

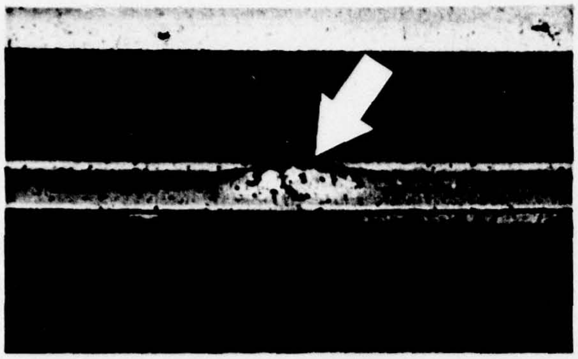

Figure B-1 T-58 Engine Transport Trailer Exfoliation

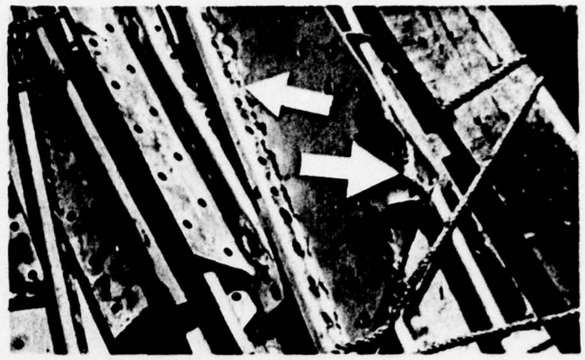

Figure B-2 E2A Aircraft Lifting Sling Exfoliation

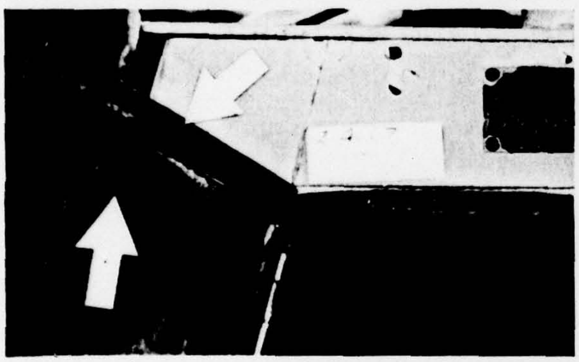

Figure B-3 Typical Delamination on Enclosure Door

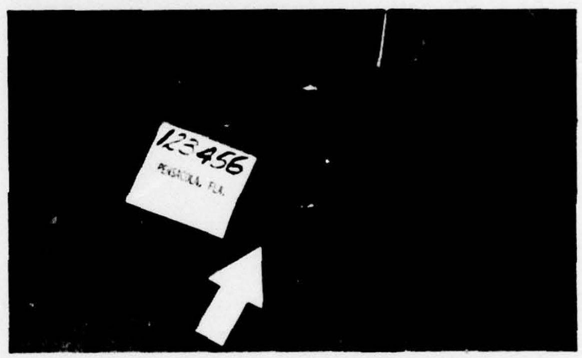

Figure B-4 Repaired Door Latch Rusting Badly

Figure B-5 Instrument Panel Chipped and Rusting in Areas of Fasteners

Figure B-6 Corrosion in Steering Wheel

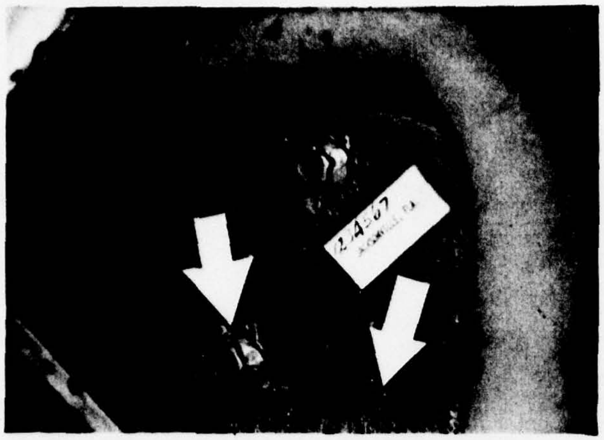

Figure B-7 Typical Delamination - Cosmetic Overcoating/ Inadequate Preparation.

Figure B-8 Water Entrapment - Pool Inside Loaded Compartment No Rain For 10 Days.

Figure B-9 Water Entrapment - No Drain - Sediment and Corrosion Products

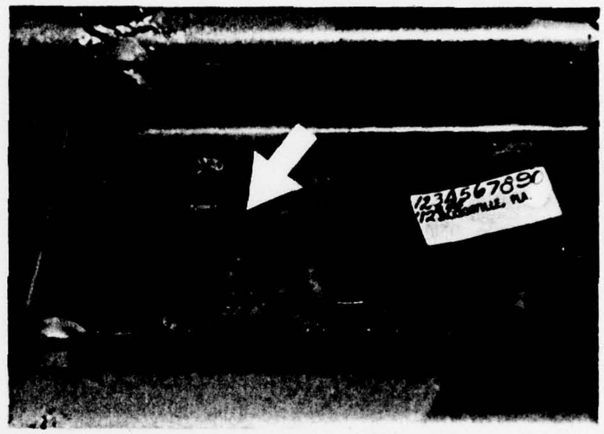

Figure B-10 Water Entrapment Caused Corrosion and Delamination.

Figure B-11 ***Water Entrapment*** **Capillary Between Mating Surfaces.**

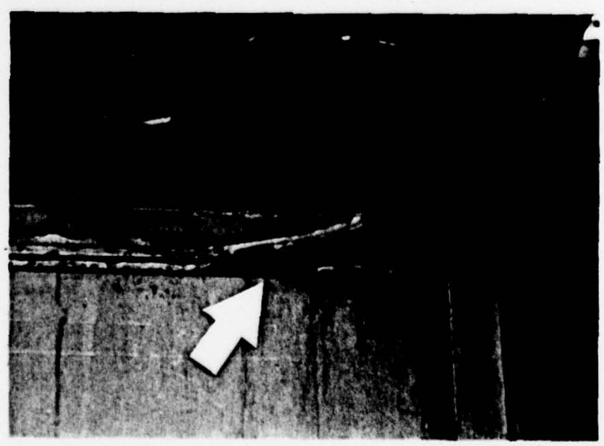

Figure B-12 **Water Entrapment Induced Corrosion.**

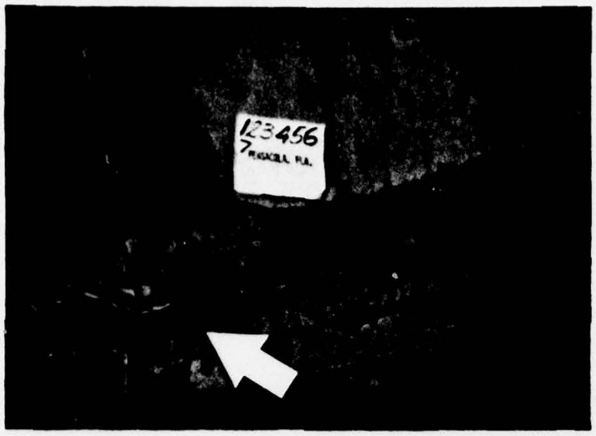

Figure B-13 Water Entrapment - Access Door Hinge.

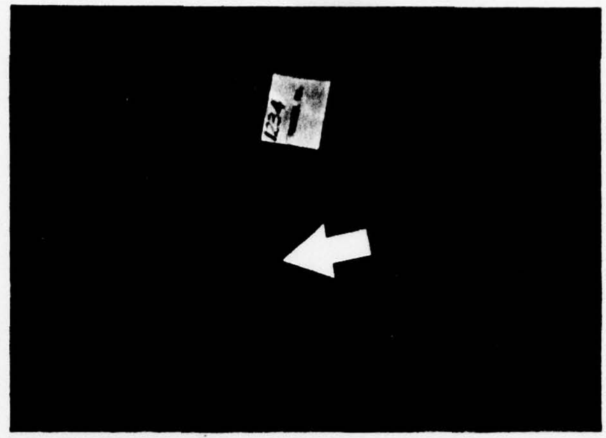

Figure B-14 Scratches Through Coating of MIL SPEC TT-E-489 Alkyd Enamel.

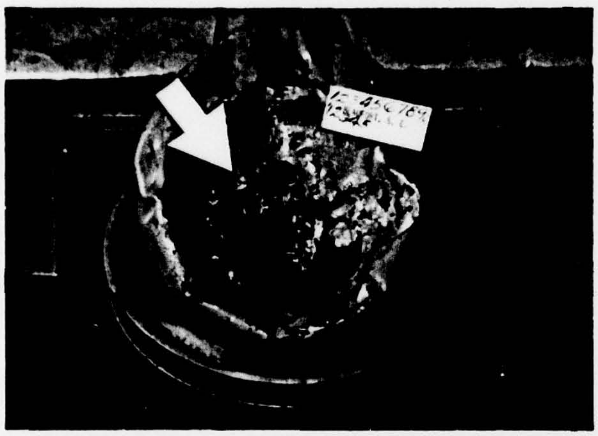

Figure B-15 Impingement - People Induced on TA-75A Tractor Air Filter.

Figure B-16 Impingement on TA-75 Aircraft Tow Tractor

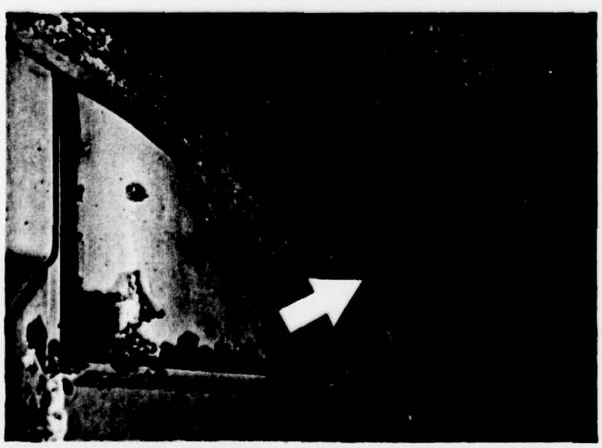

Figure B-17 Particulate Impingement on Utility Tractor

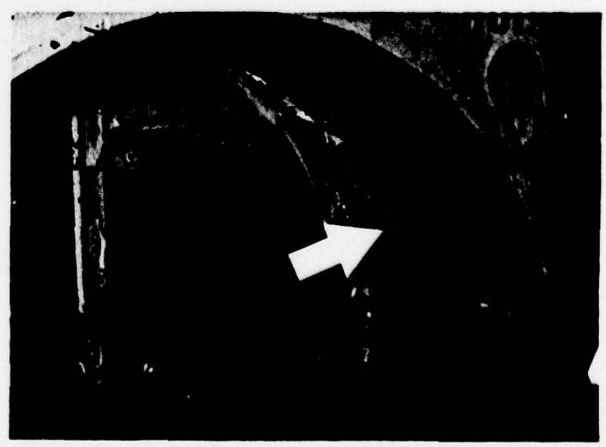

Figure B-18 Surface Erosion in Wheel Well of MD-3 Tractor

Figure B-19 Condensation Caused Corrosion on NF-2 Instrument Case

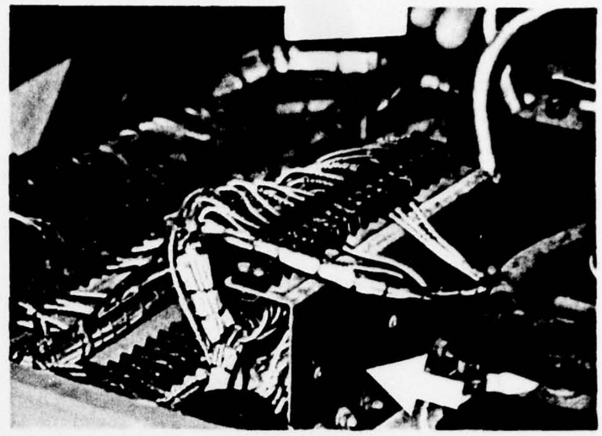

Figure B-20 Electrical Compartment Corrosion of Terminal Strap Support Bracket

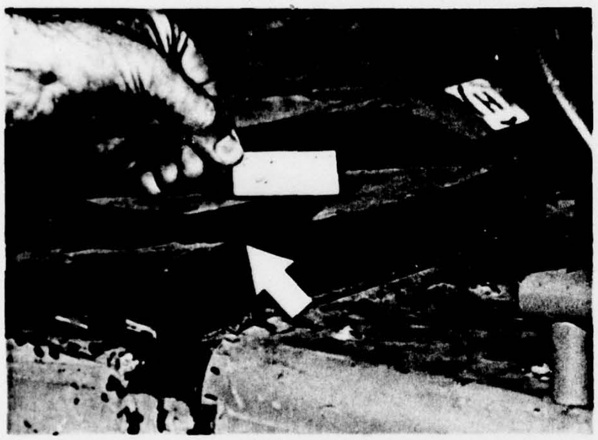

Figure B-21 SATS Weapons Loader - Bent Top Cover

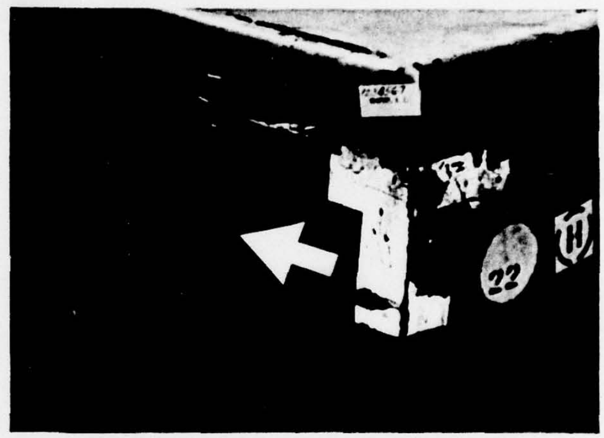

Figure B-22 GHCH Oxygen Recharge Service Trailer - Broken Cover Latch

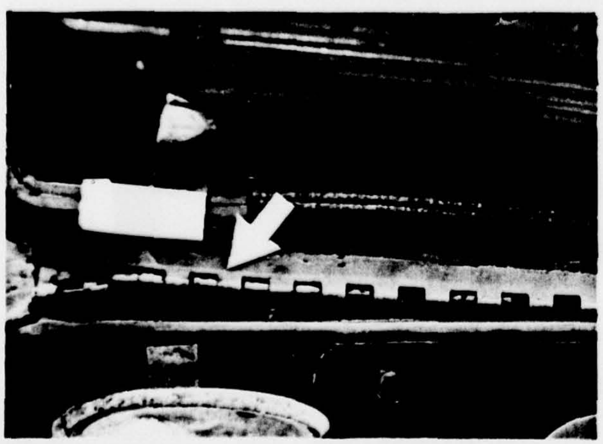

Figure B-23 SATS Weapons Loader - Bent Hinge on Engine Compartment Cover

Figure B-24 TA-75 Tow Tractor - Battery Access Door Damaged - Fasteners no Longer Engage

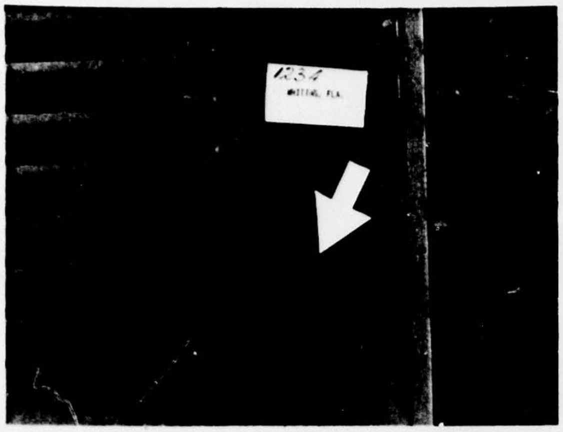

Figure B-25 Hydraulic Test Stand - GGE3 Battery Access Door - Acid Corrosion

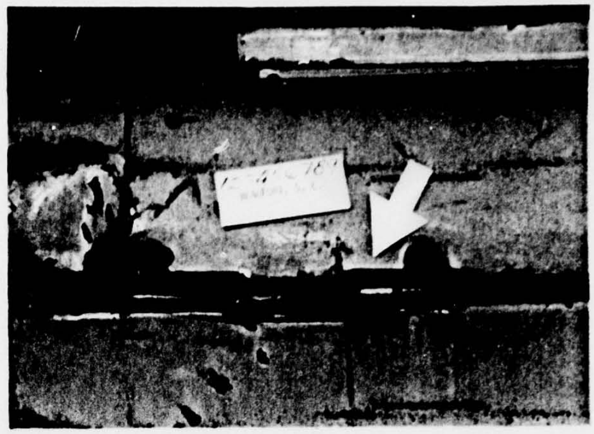

Figure B-26 GFBE Air Compressor - Joy Mfg. Co. - Damaged Door Hinge

Figure B-27 GFBE Air Compressor - Joy Mfg. Co. - Damaged Hinge Support Member

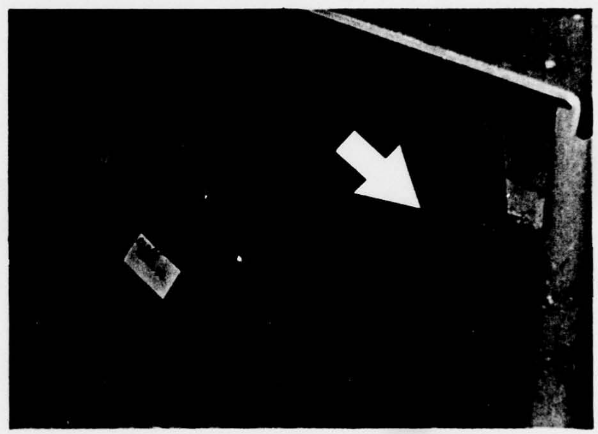

Figure B-28 TA-75 Tow Tractor - Inaccessible Area for Proper Surface Preparation/Coating

Figure B-29 Tow Tractor Battery Compartment - Acid Induced Corrosion

Figure B-30 MMG-2 Inet Sprague Motor Generator - Battery Compartment Corrosion

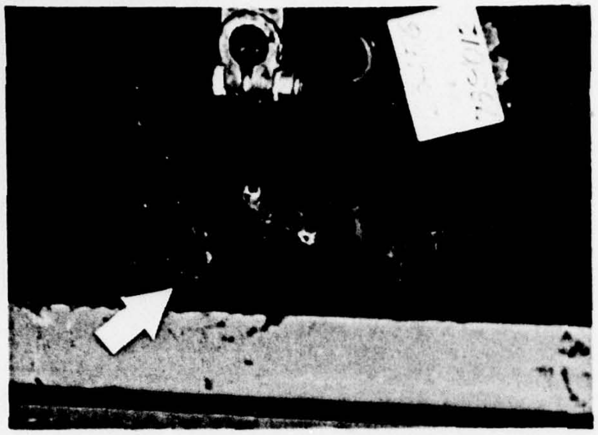

Figure B-31 TA-18 Tow Tractor - Battery Compartment Corrosion

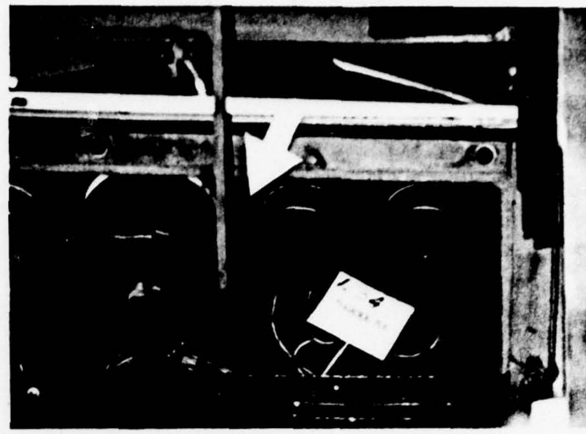

Figure B-32 Mobile Electric Power Plant - Instrument Case Corrosion

Figure B-33 Engine Removal Trailer - Piston Rod Corrosion

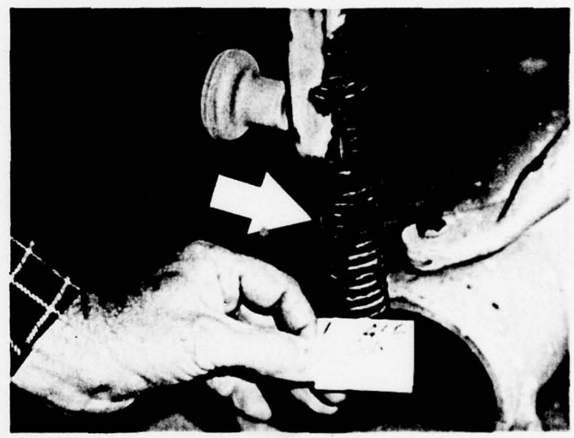

Figure B-34 AERO 51-B Munitions Handling Trailer - Exposed Screw Unprotected

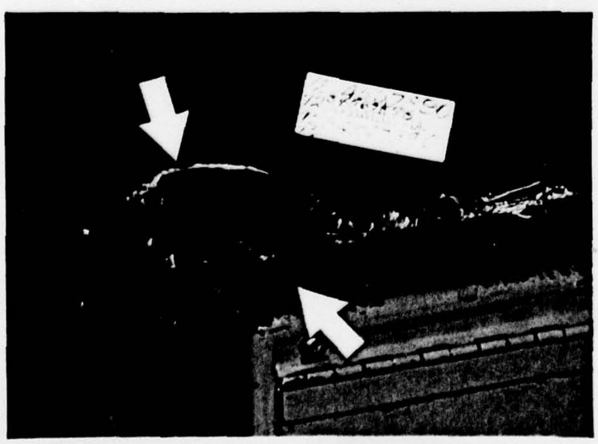

Figure B-35 Seat Cushion from NC-12 MEPP - Design Deficiency

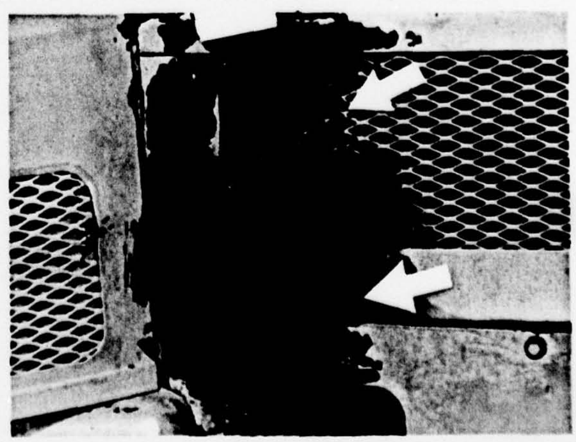

Figure B-36 SATS Weapons Loader - Corrosion from Muffler

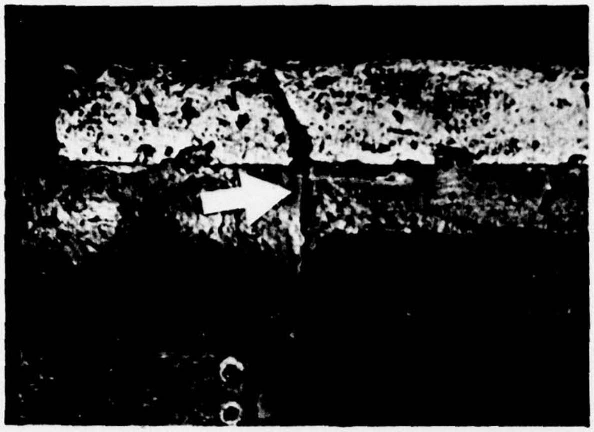

Figure B-37 Air Start Unit from MD-3 Tow Tractor - Fatigue Crack in Frame

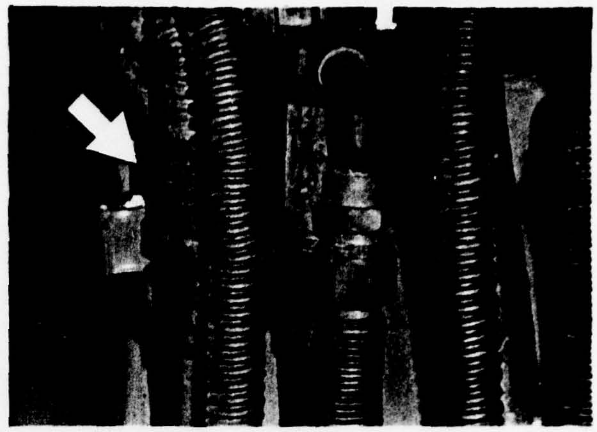

Figure B-38 O_2 Charging Cart - Fitting Corrosion

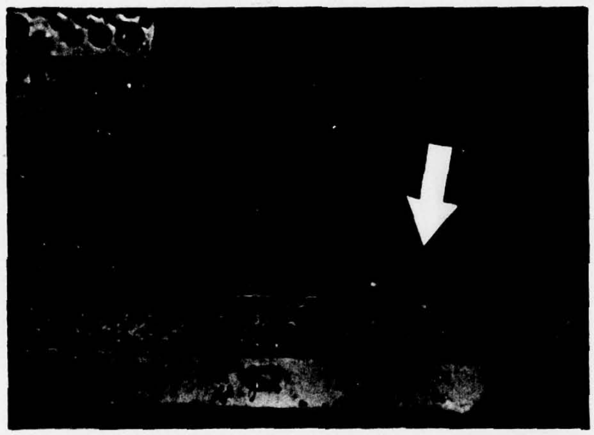

Figure B-39 Weathered Surface Coating - MD-3 Aircraft Tow Tractor from Shipboard

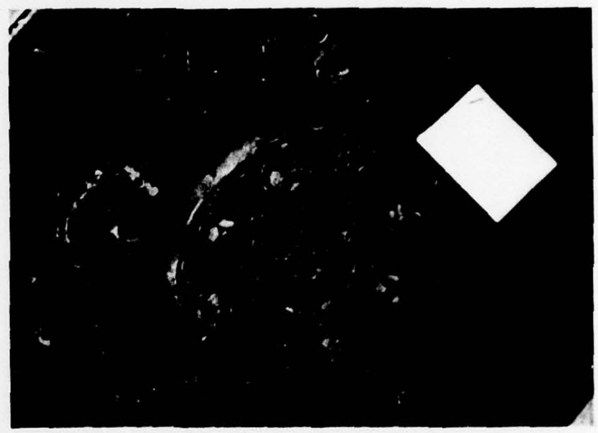

Figure B-40 NC-5 Mobile Electric Power Plant Wheel - Effects of Weathering

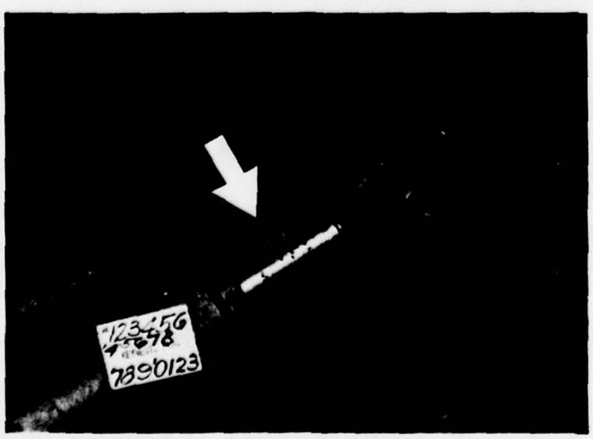

Figure B-41 Aero 33-D Bomb Truck - Pitting Corrosion on Piston Rod

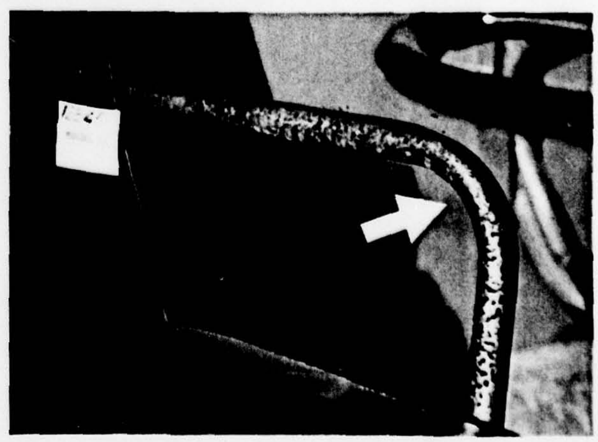

Figure B-42 TA-75 Aircraft Tow Tractor - Pitted Arm Rest

CONTROL OF CORROSION IN GROUND SUPPORT EQUIPMENT (FINAL)

NAEC-GSED-119
A/T A3400000/051B/
7F41461400

Reports the findings and presents recommendations resulting from an investigation made to determine the extent of and the reasons for corrosion on Navy aviation ground support equipment. Cost analysis data and results of an extensive on-site survey of Navy activities are also presented. Data relating to corrosion control methods, materials and equipment are included.

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